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Hydrospace-Challenger, Inc, San Diego, Calif

Prepared for

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The Environmental Protection Agency has under way a study of an airport noise regulation to establish a mechanism for limiting the noise exposure in communities around airports. The regulation may take many forms, but will include the options of quieting the source, modifying the airport operational plan, and land use remedies. The purpose of this study is to characterize, in depth, the many facets of monitoring that might be utilized in the implementation of an airport noise regulation.

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HYDROSPACE-CHALLENGER, INC.

Volume I

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Prepared for

ENVIRONMENTAL PROTECTION AGENCY

under

Contract No. 68-01-2686

Revised September 1974

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Section 1
INTRODUCTION

The Environmental Protection Agency in its role of proposing regulatory action with regard to airport noise to protect the public health and welfare has under way a study of an airport noise regulation.

The purpose of the airport noise regulation is to establish a mechanism for limiting the noise exposure in communities around airports. The regulation may take many forms, but will include the options of quieting the source, modifying the airport operational plan, and land use remedies. The goal of the airport regulation itself is to provide a quantitative framework within which all levels of government and affected persons can work together to reduce existing and prevent new noise exposure situations inconsistent with public health and welfare.

An integral part of the implementation of an airport noise regulation will be the means by which progress in controlling or reducing the noise impact can be monitored. Actual measurement of the noise environment and related parameters is expected to be required in order to: 1) confirm actual progress in controlling the noise exposure at various points on the ground and 2) to provide a tool for controlling individual facets of the airports' implementation plan which require cooperation by others, such as aircraft operators.

The purpose of this study is to characterize, in depth, the many facets of monitoring that might be utilized in the implementation of an airport noise regulation. This study has as its primary goal the following objectives:

a. Develop a comprehensive list of evaluation criteria to be used in developing an airport noise monitoring plan.
b. Develop a set of rating indices for the evaluation criteria above to provide rank ordering of effectiveness or applicability.

c. Provide a background report on the basic characteristics, mode of application, and effectiveness of airport noise monitoring systems in operation in this country and abroad, plus a description of any system monitoring operation or operational procedures.
d. Develop the conceptual framework of several promising alternative monitoring approaches and/or systems.
e. Identify areas where additional studies may be required to evaluate unique monitoring alternatives.

Although the classical methods of airport noise monitoring have consisted of some sort of measurement of the acoustical signal from the noise source, this study is not limited to a review of acoustical instrumentation systems. Every effort has been made to consider all facets of the noise problem, which include: 1) the noise and operation of the source, 2) the path, 3) the receiver, 4) the land use, and 5) the discussion of a number of monitoring concepts applicable to these areas.

The completed noise regulation and the resulting airport noise implementation plan are concerned primarily with aircraft as noise sources, operational procedures, and land use controls. The necessity to monitor for compliance, as well as to evaluate effectiveness of the regulation, is an important part of the regulation. However, monitoring should not be considered an end result in itself. Monitoring systems and procedures must logically relate to the requirements and goals of the noise regulation. This study, therefore, will not be purely a technical dissertation on airport noise monitoring, but will define a minimum/maximum range of monitoring requirements to enable airport proprietors to propose monitoring programs that are effective, economical, and reliable.

1.1 GENERAL MONITORING REQUIREMENTS

The basic requirements and design concepts of the noise regulation monitoring include:

a. A noise monitoring plan would be developed by individual airports as part of their long-range implementation plan.

b. Minimum legal requirements for monitoring would be part of the final noise regulation.
c. Monitoring would be sufficient to measure the progress in controlling noise exposure at the airport in question.
d. Monitoring should be sufficient to evaluate the effectiveness of each facet of the airports' implementation plan.

These basic requirements lead to the more critical issues when applied to a wide range of airports and the unique situations thereof. Some of these are:

a. Several monitoring options and/or alternatives should be available to the airport proprietor.
b. Monitoring should provide flexibility in terms of site location and must be consistent with the airport implementation plan.
c. Monitoring systems should provide a range of data output to enable the measurement of cumulative exposure, not only in terms of acoustic parameters but operational procedures as well.
d. The reporting requirements must reflect a variety of uses for the data.

The implementation of a monitoring plan may require one or a combination of alternative monitoring approaches.

1.2 SUMMARY OF GENERAL MONITORING CONCEPTS

The typical aircraft noise control options available for use in regulating noise have been discussed in detail in a number of reports compiled by the Environmental Protection Agency. The options fall clearly into four areas: 1) source, 2) path, 3) receiver, and 4) land use. It would, therefore, appear reasonable to apply these same areas to the concept of types of airport noise monitoring. Therefore, monitoring tends to become one of two types, acoustic and/or operations.

1.2.1 Acoustical Monitoring

Acoustic monitoring is defined as the measurement of the noise level

of aircraft operations at some point on the ground. This implies the classical concept of airport noise monitoring where the acoustic energy is evaluated using some sort of sound level measurement instrumentation. In this instance the end product (noise) is quantified. The methodologies of acoustic monitoring can cover a wide spectrum of functions.

The least complicated function is to have equipment which makes a yes/no decision regarding too much or not too much noise or, in other words, is some permissible engineering value exceeded. This, however, is often too simple an approach since the noise levels of various aircraft are different and not all airports have the same traffic mix. This brings into the picture the need for the definition of noise from any significant single event (usually a flyover or single event of interest, either on approach or departure). The summation of a number of single events at a point on the ground then provides further information as to the longer term fluctuations of noise. The cumulative or long-term monitoring yields acoustic information that tries to account for the variety of operations that can occur over a significant period of time. Further, the cumulative noise exposure is of importance in terms of the pervasive long-term noise in many areas under various conditions over long periods of time and the correlation of known effects of the noise environment on the individual and the public.

Although the monitoring of single events serves to verify individual aircraft source controls and provides guidance in terms of the effects of certain operational changes, the cumulative is more applicable to the requirements of planning and assessment of the effectiveness of applied noise controls.

The degree to which any monitoring methodology (single event, continuous, or spot-check) should be implemented would depend in large part upon the individual characteristics of the airport/community under evaluation.

One of the basic premises of this study is that adequate monitoring requirements must be identified for the entire spectrum of airports. Airports are classified as large, medium, and small hubs handling air carrier operations and general aviation airports with and without business jet operations. The extent of a noise impact problem at any one of these sizes of airports is

often related to the presence of housing within the immediate area of the airport operations influence area or plans to develop. This area can be defined as those locations on the ground over which aircraft approach, depart, and otherwise fly over during touch-and-go's or other close-in flight procedures. It is obvious that one needs to first define the influence area which is a combination of operations information and existing and future land use. For those airports using the computerized noise model during the development of the implementation plan, the noise influence can be defined as a function of the noise contours and land use maps. However, not all airports will use the program; thus the influence area may be determined using such items as land use maps, complaint histories, or spot measurements.

For the purposes of this study it will be assumed that the following classes of coverage will exist:

a. Portable site.
b. Fixed site.
c. Portable + fixed site combination.

The number of sites may be dependent upon the type of coverage desired (fixed versus portable) and upon the degree of noise encroachment (moderate, severe, adverse). Further considerations of geographical features, land use, runway layouts, and operational patterns must be considered.

Considerations of airport ownership/operation and the ownership of impacted land will, in some respects, yield various options with regard to monitoring methodologies. Since typical ownership can range from private to governmental agencies, monitoring may be dealt with on a local, regional, or federal level.

The size of the airport will often dictate the size and complexity of airport noise monitoring entered into. Very large airports have the impact and also the funds and technical expertise available, whereas small general aviation airports are usually run with minimum staffs. The variety of ownership and the resultant variations in staffing and funding address the question of the technical abilities and methods of equipment acquisition.

The actual monitoring work can be performed in the following manner:

a. Service type contract to outside vendor.
b. In-house.
c. Agreements with local, state, and federal entities.

Equipment acquisitions can be as follows:

a. Lease/rental.
b. Outright purchase.
c. Cost shared with other agencies.
d. Loan from higher governmental authority.

Data requirements will vary according to the local situation. Possible data uses include:

a. Verification of estimated contours.
b. Input for planning decisions, both local and regional.
c. Input into policy decisions regarding airport operations and growth.
d. Information for industry use.
e. Public information.

The collection, storage, and dissemination of noise monitoring information will require careful forethought as to the forms and procedures necessary to convey a useful and accurate picture of the situation. As a minimum, the data should be reported in a format that contains the following information:

a. Date of measurement period(s).
b. Location of measurement site(s).
c. Unit of measure and its appropriate time of day.
d. Single measurement information (where applicable):
    1. Source identification.
    2. Source to receiver estimated distance.
    3. Source operating conditions.
e. Instrumentation used.
f. System accuracy and precision.
g. Date of last calibration.
h. Meteorological conditions.

1.2.2 Unit of Measure

The unit of measure to be used in the implementation plan is expected to be among those currently in the literature and is assumed to be specified for a particular situation in the regulation. Although a variety of measures are now used to assess noise, the basic physical characteristics of sound are: 1) magnitude, 2) frequency distribution, and 3) time distribution. This information will serve as basic input to any equation devised as a measure of community response. The complexity of the instrumentation is directly related to the unit of measure desired.

a. Single measure of amplitude and frequency.
b. Time history values.
c. Single cumulative magnitude, frequency, and time value.
d. Statistical distributions.

For the purposes of this study it is assumed that one or more of the above types of units of measure will be required.

1.2.3 Operational Monitoring

The noise option controls for airports include a number of remedies which are primarily operational in nature. Suggested operational options include:

a. Approach and departure paths applicable to specific runway and, if desired, to specific parts of the 24-hour day.
b. Noise abatement flight procedures.
c. Rules limiting the times and places on airport property where engine ground runups are allowed.

All of these options can be monitored by the acoustical means; however, in many cases, the noise measurement is an indirect measure of whether or not the particular remedy has been applied.

For direct measurement of the effectiveness of operational controls, the measurement of operational parameters is suggested. The most obvious is a measure of flight path for those cases where approach or departure paths are specified. The equipment to be utilized might include existing and future radar and navigational aids. All of these instruments are usable in one form or another to accomplish two-segment or controlled flight paths.

The monitoring of the results of using such systems could be accomplished using tracking radars or a combination of television and radar. The establishment of operations quotas requires up-to-date and accurate counts of operations obtainable from the industry using the airport. Schemes for counting aircraft in real time include beam interference such as electric eyes or utilization of installed transponders. The ultimate in monitoring is, of course, somehow monitoring the operational parameters of the noise source, namely the aircraft. The idea is to establish that noise abatement procedures are being followed by the individual pilots, or, in other words, to provide the pilot a check on his own acoustical performance in terms of parameters he is most familiar with. The suggested method is applicable to the large commercial aircraft having flight data recorders (FDR). The more recent FDR's have the capability to record on them a number of aircraft/engine performance parameters which are applicable to the area of acoustics. These parameters include flag position, altitude, airspeed, engine thrust, and heading. The problems involved in getting access to these data and their processing have yet to be determined. However, one can envision the ultimate in monitoring by transmitting the acoustical signal from each site over a proximity radio to be recorded on a spare channel of the FDR. This would provide a comprehensive correlation of all pertinent parameters. The theory here is that if the industry has followed noise abatement procedures within allowable safety tolerances and still causes a violation and an impact above specified levels, then there is nothing more that can be demanded of the industry. The use of flight data recorders with and without acoustic input bears further detailed study to evaluate all the advantages and disadvantages.

1.2.4 Operational Unit of Measure

The units of measure to be considered for operational monitoring include:

a. Number of operations.
b. Flight path deviations.
c. Ground track deviations.
d. Aircraft/engine performance deviations from specified values.

1.2.5 Miscellaneous Monitoring

As the passenger demand increases and as general aviation activity grows, airports will be faced with the growth problems. Likewise, the land use within the airport noise influence area can be expected to change. Over the long term then, another form of monitoring is required. This monitoring would evaluate the land usage, zoning shifts, and population migration. Although these trends are not directly detectable using conventional acoustical instrumentation, this information is nevertheless important.

1.2.6 Summary of Considerations

The foregoing narrative contains a number of considerations to be evaluated in the overall context of monitoring. A summary of these considerations which are used in the monitoring decision-making process follow:

a. Facility factors:
   1. Runway configuration.
   2. Runway length.
   3. Navigation aids.

b. Operations factors:
   1. Aircraft mix.
   2. Yearly operations.

c. Administrative factors:
   1. Proprietorship.
   2. Administrative personnel.
   3. Technical personnel.
   4. Acoustic experience.
   5. Financial.
   6. Data reporting.

d. Demographic factors:
   1. Population trend.
   2. Land use.

e. Noise related factors:
   1. Complaint history.
   2. Encroached area.
   3. Controls in use.
   4. Controls proposed.

f. Meteorological factors:
   1. Temperature.
   2. Precipitation.
   3. Relative humidity.
   4. Wind.

g. Legal factors.

h. Strategic purpose of airport, dependence of area on airport for transportation and commerce.

Section 2
SURVEY OF EXISTING AIRPORT MONITORING SYSTEMS

The measurement and analysis of aircraft noise varies in level of sophistication, from simple hand-held level meters to computer controlled automated systems having a variety of output modes. Due to the dynamic nature of airport and aircraft operations, the measurement of noise from such operations has resulted in a number of measurement systems. In order to determine the range of systems and methodologies, a survey was conducted of current airport noise monitoring systems. A questionnaire was sent to those airports listed in Table 1 and those manufacturers listed in Table 2. The form of the questionnaire is given in Volume II as an aid to understanding the responses requested. A filled-in form for the system in use at San Diego's Lindbergh Field was included in the mailing.

Table 1. Airports Surveyed

United States	Foreign
New York (Kennedy)	London (Heathrow)
La Guardia	Gatwick
Newark	Zurich (Kloten)
Los Angeles	Stuttgart
San Jose	Frankfurt (Rhein-Main)
Orange County	Munich
San Diego	Paris (Orly)
Oakland	Nice
Boston (Logan)	Amsterdam (Schiphol)
Cleveland (Hopkins)	Tokyo
	Osaka

Due to the extensive information required and the time constraints of this study, the response to date has been limited. A summary of the status of the survey is given in Table 3. In some cases, equipment manuals were provided rather than the completed form. The manuals were reviewed and the appropriate data extracted and filled in on the survey form by this contractor. The completed survey forms are included in Volume II and can be referred to for specific details.

Table 2. Manufacturers Surveyed

United States

Hewlett-Packard (Palo Alto)
B&K Instruments (Cleveland)
General Radio (Massachusetts)
Digital Acoustics (Santa Ana)
Tracor Instruments (Texas)
Bolt Beranek & Newman (Cambridge, Massachusetts)
Hydrospace-Challenger, Inc. (San Diego)

Foreign

Bruel and Kjaer (Denmark)
Hewlett-Packard GmbH (West Germany)
Rhode & Schwartz (Germany)

Table 3. Results of Survey to Date

Replies Received	Nature of Reply
Orange County Airport	Forms completed
Lindbergh Field	Forms completed
San Jose Airport	Forms completed
Port of Oakland	Report describing system/methods
Munich-Riem Germany	Forms completed
B&K Instruments	Forms completed
Hewlett-Packard GmbH	Manual for LAX and letter reply
General Radio	No system for monitoring
Schiphol Airport (Amsterdam)	Forms completed
Stuttgart, West Germany	Forms completed
Frankfurt, Germany	Forms completed

The following narrative will contain a summary of the basic characteristics, mode of application, and effectiveness of airport noise monitoring systems that are in use in the United States and abroad. In addition, a following section will describe several pieces of equipment that can be used to monitor noise and that can be applied to airport situations.

2.1 EXISTING AIRPORT SYSTEMS

Presently, the airport noise monitoring systems in general use fall into the following categories:

a. Fixed-location remote site with signal transmission to a central processing system.
b. Portable equipment mounted in a van.

The fixed systems consist of two basic types: 1) systems designed around existing general purpose hardware and 2) systems that were especially designed for monitoring purposes.

Of the respondents to the survey, the system in use at Oakland Airport can be classified as portable. The equipment used requires that an operator be present and is essentially a hand operation in that the flyover data are recorded on a level recorder, the peak dBA levels noted, and the appropriate duration data obtained by the observer. All computations for SENEL, HNL, and CNEL are performed using a programmable calculator. Another option available involved the use of a statistical distribution analyzer. Using the following equation the hourly noise levels (HNL) were computed from the statistical distribution analyzer register counts.

$$HNL = (M - P) + 10 \log_{10}\left(\frac{\sum_{j=1}^{j=12} K_j A_j t_j}{\sum_{j=1}^{j=12} t_j}\right)$$

where
- M = maximum record level
- P = potentiometer range
- L = threshold level = $(M - P)$
- t_j = count of seconds in the jth register
- $A_j = K_j \times 10^{P/100(j - 3/2)}$
- $K_j = 1$, for $2 \leq j \leq 11$
- $K_j = 0$ elsewhere

The system acquisition equipment is of laboratory quality and can be used for noise monitoring purposes other than airport noise. The use of such equipment, however, does not result in any degree of automation and is suitable, therefore, for limited use in regards to airport noise monitoring. Although such an approach provides an excellent diagnostic tool, its use for large scale monitoring would result in excessive personnel demands.

Examples of the typical fixed-location remote site with signal transmission to a central processing system comprise the remainder of the existing systems for which replies to the survey have been received.

Because of a definite advancement in the state-of-the-art, the systems will be discussed in two categories. The first category will be those systems which transmit a signal over phone lines that is amplitude proportional to frequency. See Figure 1. The second category will be those systems which transmit digital data over the phone lines.

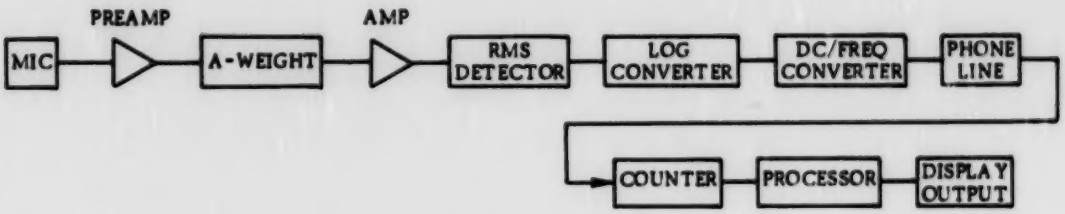


Figure 1. Analog Signal Transmission

Note that the signal is in some analog form until the processor converts to a digital word. In all cases data is transmitted over the phone line in a frequency format. Thus, at central, a counter is used to determine the decibel level. This approach was used for the design of all Hewlett-Packard (H-P), Rhode and Schwartz, and for the Orange County systems.

Hewlett-Packard systems are installed at the following airports:

a. Zurich, Switzerland.
b. Geneva, Switzerland.
c. Sydney, Australia.
d. Stuttgart, West Germany
e. Heathrow, United Kingdom.

f. Galwick, United Kingdom.

g. Manchester, United Kingdom.

Rhode and Schwartz systems are installed at the following airports:

a. Munich-Riem, Germany.

b. Rhein-Main Airport, Frankfurt, Germany.

c. Nice Airport, France.

d. Schiphol Airport, Amsterdam, Netherlands.

The primary difference between the two systems was the concept of time sharing the counter. The two schematics given in Figure 2 will serve to illustrate. The location of the scanner is, in this case, very critical.

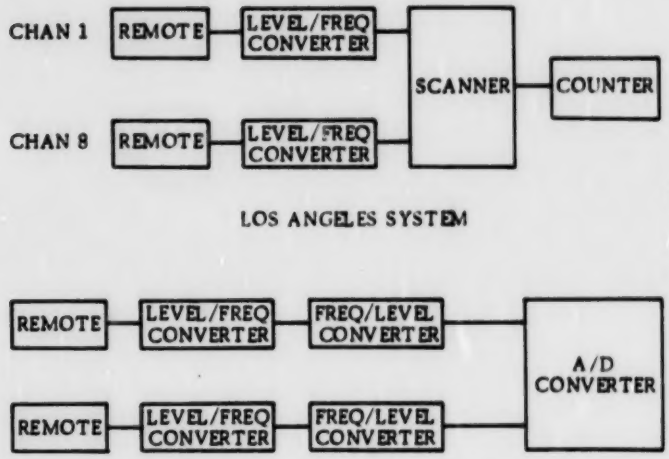


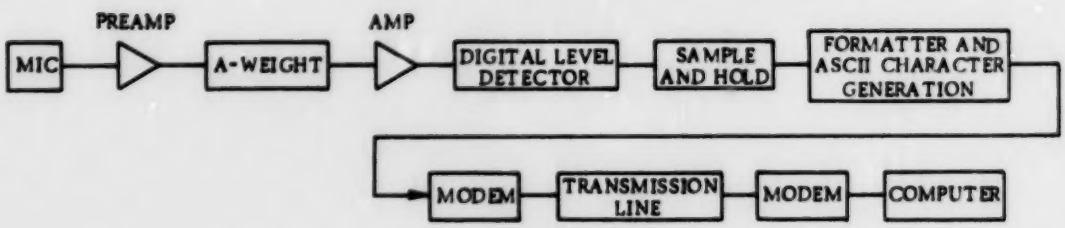
Figure 2. Comparison of Two Data Scanning Methods.

Due to the time sharing of eight channels, the LAX system data acquisition timing was as follows. For every half second, all eight channels were scanned for 20 msec each and the remaining time devoted to data processing. This sample period is extremely short and subject to erroneous readings due to noise on the telephone lines. The counter measurement time was 10 msec. The use of phase-lock loops may have solved some error problems for this system where the quality of phone line transmissions was affected by bursts and shots.

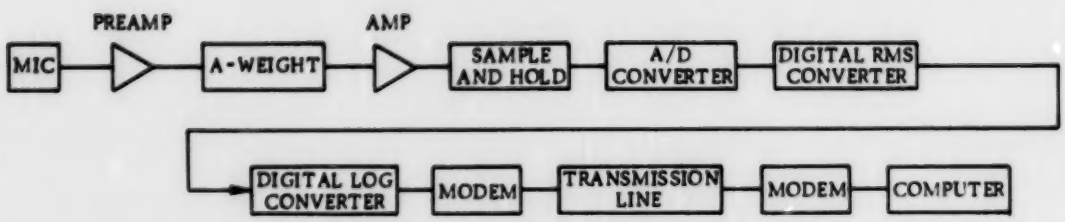
On the other hand, the Munich system is sampled once a second by a counter for each line and does not appear to be susceptible to phone line problems.

Another comment worthy of note is that these systems are designed for use with a single pair of phone lines; thus, such functions as direct listening control are performed at the expense of stopping data acquisition.

The systems that fall into the second category represent two of the latest designs and installations. Typical schematics for the San Jose and San Diego Lindbergh systems are given in Figure 3.



SAN JOSE SYSTEM



SAN DIEGO SYSTEM

Figure 3. Digital Data Acquisition Schematics

Note that digital detection is being performed at the remote site. This has the advantage of providing wider dynamic range (75 to 90 dB) and somewhat simplifying the transmission of data over the phone lines. Further, the San Jose system transmits the message at the rate of two per second at a bit rate of 110 baud. The message content is 11 bits per character using five characters. The San Diego system, on the other hand,

sends two messages per second at a bit rate of 32 baud, each message containing 14 bits.

Each of these systems are rather more sophisticated than previous designs due to the use of dual telephone lines and the requirements for screening out non-aircraft noise and some rudimentary tracking requirements to sense traffic pattern direction and set violation limits. The San Jose system uses software screening and sequence of microphone detection to accomplish the above requirements. The San Diego system is similar except that a hardware filter which detects energy above a set level in a selected octave band is used to aid in determining the presence of an aircraft. Sufficient energy in this filter will set a bit which is transmitted as part of the data message.

The fixed-site central processing systems can become quite sophisticated in terms of functions and controls. The present state-of-the-art is rapidly advancing. The systems drive displays and provide a number of optional outputs limited only by overall cost considerations.

Other auxiliary features of these newer systems are the requirements for identifying single event noise level violators. Two approaches are used. The first, in the San Jose system, relies on a voice-actuated relay which records all tower conversations on low-speed tape recorders, along with time of day. In the event of a violation, the computer prints out noise level duration, time of day, and any other parameters of interest. The tape can then be searched for the approximate time frame and a determination made regarding which aircraft, operating in the area, was most likely to have caused the violation.

The second approach, in use at San Diego/Lindbergh Field, uses a loop and reel-to-reel tape recorder. The loop recorder operates continuously, recording four channels of data: 1) WWV time of day, 2) tower conversations, and 3) two channels of analog data from microphones at each end of the runway. The loop is 10 minutes in length; thus, by placing the playback head before the recording head, one always plays back 10-minute old data. In the event of a violation, the computer not only prints out pertinent information on the printer, but commands the transfer of the data on the loop recorder

to the reel-to-reel tape recorder. The end result will be a recording on the reel-to-reel recorder consisting of 10 minutes of data before the time of the violation and 5 minutes of data after the time of the violation. Thus, each recording on the reel-to-reel machine represents a violation. Searching for the aircraft identification is somewhat simplified.

As of this date, a number of airports have not replied to the survey. As an interim measure, it is suggested that the report entitled "A Survey of Aircraft Noise Standards and Monitoring Systems at International Airports," by the City of Inglewood, California, July 1972, serve until such time as further replies are forthcoming. A summary table from that report is included as Table 4. This information will be updated as new information becomes available.

A summary of the data processing for a number of systems is given below:

London	Maximum allowable level
Kloten	Level exceeds threshold Alarm on violations Reports L_{eq} - hourly, 8 hours, 24 hours
Stuttgart	Maximum levels and duration - hourly Eight hourly daily noise levels
Frankfurt	Individual noise by volume, time history, and L_{eq} hourly
Orly	Single events
Osaka	Maximum allowable levels
Tokyo	Noise levels displayed
J.F.K.	Transmit excess levels and violations noted
Orange County	Single events or cumulative noise - hourly or daily Single event violation
LAX	Single events and cumulative levels
Munich	Single event violations L_{eq} - hourly and daily
San Jose	Single event violations HNL, CNEL
Zurich	Total duration above limit - hourly Eight hourly daily exposure levels Number of events
Geneva	Same as Zurich
Sydney	Histogram on line Noise exposure off line

Table 4. Summary of Older System Survey

Airport	Operations 1970	Type of Aircraft	Monitoring System	Noise Standards	Procedures	Night Restrictions	Enforcement Penalties
LONDON (HEATHROW)	270,360	707,727,737, 747,DC-8,DC-9, BAC-111,VC-10, Trident	13 fixed monitors. Installed 1960.	110 PNdB(7a.m.-11p.m.) 102 PNdB(11p.m.-7a.m.)	Approach: Radar monitoring	No general aviation jets from 11 p.m.-7 a.m. Quota of 3500 commercial jets in summer.	No penalties. Airline notified.
ZURICH	130,470	707,727,737 747,DC-8,DC-9 BAC-111,IL-62, VC-10, Comet, TU-104	9 fixed monitors. Several mobile units. Autoratic central processor. Installed 1964	99 dBA (6a.m.-10p.m.) 95 dBA (10p.m.-6a.m.)	Approach: at or above 3° Preferential runway. Departure: Thrust reduction. Maximum climb	10 p.m. - 6 a.m.: no thrust reverser. No run-ups	No penalties. Airline notified. Pilot reprimanded. Violations published monthly.
STUTTGART	117,630	707,727,737, DC-8,DC-9, Caravelle, Trident,BAC-111	7 fixed monitors. Automatic central processor.	96 dB(A) (Monitor 6) 90 dB(A) (Monitor 1)	Departure: Routing	10p.m.-6a.m.:no thrust reversers. No jet take-offs except 10 p.m.-11:30 p.m. and airmail service	No penalties.
FRANKFURT	200,000	707,727,737,747, DC-8, DC-9, BAC-111,Trident, Caravelle	13 fixed monitors. Automatic central processor. Installed 1964	Daily variable standard.	Standard instrum. departure routes are minimum noise routes	None	Pilot ... be fined.
PARIS (ORLY)	190,700	707,727,737, 747,DC-8,DC-9, Caravelle,BAC BAC-111, Trident	3 fixed monitors. Graphic level recorder at central station.	Compare measured dBA or PNdB with calculated level for each type.	Departure: thrust reduction. Maximum climb.	Commercial jet curfews 11:30 p.m.-6 a.m.	No penalties. Airline notified and explanation requested.
OSAKA	150,730	707,727,737, DC-8,DC-9, CV-880,YS-11, F-27	3 fixed monitors. Automatic central processor.	100 dBA(6:30a.m.-7a.m.) 107 dBA(7a.m.-8p.m.) 100 dBA(t/o)(8p.m.-10:30p.m.) 107 dBA(lands)(10:30p.m.-10:30p.m.) 75 dBA(10:30p.m.-6:30 a.m.)	Departure: Routing. Performance	Jet curfew between 11 p.m. - 6 a.m.	No penalties. Airline notified and explanation requested.
TOKYO	163,300	707,727,737 747,DC-8, CV-880,YS-11	2 fixed monitors. Central station installed 1966	None	None	Jet curfew between 11 p.m. - 6 a.m.	No penalties.
NEW YORK (KENNEDY)	408,800 (1968)	707,727,737 747,DC-8,DC-9, DC-10,VC-10, BAC-111	3 fixed monitors. 3 mobile monitors. Automatic central station. First system installed 1960. New automatic system 1971	112 PNdB at residential areas.	Approach: Routing Departure: Routing, Performance (thrust,weight)	10 p.m. - 7 a.m.: preferential runways.	No penalties. Airline notified.
SANTA ANA (ORANGE COUNTY, CALIFORNIA)	555,000	737, DC-9, Jetstar,HS-125, F-27,Twin-Otter, Light aircraft	5 fixed monitors. Automatic central processor. Installed 1970.	California State Standards	Departure: Routing	Jet curfew between 11 p.m. - 7 a.m.	No penalties. Operator notified.
LOS ... LES (INGLEWOOD)	516,000	707,727,737, 747,DC-8,DC-9, DC-10, L-1011, VC-10, CV-880, F-27	15 fixed monitors. Automatic central processor. Installed 1972 4 fixed monitors. 1 mobile monitor. Installed 1970.	None (Standard only for run-ups of unmounted engines.)	Approach: Preferential runway Departure: Routing	11 p.m. - 6 a.m.: No run-ups. Tower clearance for engine start-up.	No penalties.

Heathrow	Maximum level duration, histogram Correlates flight data with events
San Diego	Single event violations HNL, CNEL
Oakland	HNL, CNEL - periodically

Although the data sample is small as yet, the main performance parameters of existing airport noise monitoring systems are given in Table 5.

2.2 OTHER NOISE MONITORING EQUIPMENT

In addition to the systems currently installed at airports and those described in Section 2.1, there are a number of commercially available instruments that can be used or adapted for use in airport noise monitoring. We refer specifically to such items as:

a. Dosimeters.
b. Noise dose meters.
c. Noise classifiers.
d. Digital acoustical data acquisition systems.
e. Noise average meter.

Dosimeters are designed specifically to acquire data over the sound level range of 90 to 115 dBA for OSHA requirements. Noise dose meters are more sophisticated instruments used in conjunction with a sound level meter in assessment of risk of hearing loss, evaluation of noise annoyance, psychoacoustic research, and energy integration applications.

Noise classifiers are an acoustical amplitude analyzer which classifies noise levels into amplitude bands over a selected range of 27 dB.

The digital acoustical data acquisition system is a self contained system that measures a selected weighted sound level (A, C or flat) at intervals of 0.5, 1, or 10 seconds (or 1, 3, 10 seconds) and outputs the data on a digital cassette. Provisions are provided for time of day and event number input as well as an LED display to read the current dB value. One system has the added feature of a 40-Hz wind filter to reduce the effects of wind noise. The cassettes are played back on a reader interfaced to a computer or calculator for processing. The system dynamic ranges vary from 60 to 100 dB.

Table 5. Summary of Existing Survey as of August 1974

Airport:	Orange County	Munich	San Jose Municipal	Los Angeles International	Lindbergh Field	Oakland International
Location	Santa Ana, Ca	Munich-Riem, Ger	San Jose, Ca	Los Angeles, Ca	San Diego, Ca	Oakland, Ca
Date Installed	October 1971	October 1971	November 1973	1972*	February 1974	April 1973
Number of Sites	5	8	8	15	8	1 portable
Acoustic Sensor	Altec 688B Mic	Rhode & Schwarz	Chesapeake Instr	-	Chesapeake Instr	B&K 4149
Measurement Units	dBA	dBA	dBA	dBA	dBA	dBA
Measurement Range(s)	60-120 dB	20-140 dB	55-130 dB	40-70, 60-90 dB	40-136 dB	50 dB
Range Switching	None	Local, 50 dB ea	None	Local/remote	None	Local
Signal Processing	Analog	Analog	Digital	Analog	Digital	Analog
Data Encoding	Analog frequency	Analog frequency	ASCII digital	Analog frequency	Binary digital	Level recorder
Transmission Link	Telephone lines	Telephone lines	Telephone lines	Telephone lines	Telephone lines	None
Frequencies/Baud	600-1200 Hz	300-3000 Hz	1070-1270 Hz	620-2620 Hz	1070-1270 Hz	-
Sample Rate	11 sec	1 per sec	2 per sec	2 per sec	2 per sec	-
Central Processor/Memory	Nova 1200/8K	DEC PDP 8L/8K	Nova 1220/16K	H-P 2116C/16K	Varian 620L/100	Monroe Calculator
Operator Control/Input	18 commands	11 commands	28 commands	4 commands	21 commands	None
Displays Monitors	5 light display; audio alarm	8 panel meters; 8 status lights	Panel meters; map; status lights; audio	Status panel; audio alarm	Panel meters; map with status lights	None
Event Processing	SENEL	dBA above threshold	SENEL	SENEL	SENEL	None
Violation Identification	Teleprinter output	Teleprinter output	Teleprinter output; record tower com	Teleprinter output;	Teleprinter output; record tower & WWV	None
Non-Aircraft Reject	None	Duration 5	Software screen	None	Software screen/ hardware filter	-
Exposure Processing	HNL, CNEL	Duration above threshold	HNL, CNEL	HNL, CNEL	HNL, CNEL	HNL, CNEL
System Cost	$58,000	DM 340,000	$130,000	$210,000	$124,000	-
Manpower Requirements	1450	2000 hours/year	800 hours/year	-	840 hours/year	-
Outputs	HNL, CNEL, SENEL	Event cal hourly	HNL, CNEL, SENEL	HNL, CNEL, SENEL	HNL, CNEL, SENEL	-
Manufacturer	Northrop	Rhode & Schwarz	Tracor, Inc.	Hewlett-Packard	Hydrospace	-

* Taken out of service, 1974.

The noise average meter is a direct-reading instrument providing a digital readout of the equivalent continuous sound level (L_{eq}) of sounds over an 80-dB range.

The equipment briefly described above may be of use in monitoring airport noise assuming proper correlations can be established.

A summary of the main performance parameters of this equipment is given in Table 6.

Table 6. Summary of Specifications for Other Types of Monitoring Equipment

Type of Unit	Noise Average Motor	Noise Classification	Noise Dose Meter	Dosimeter	Digital Acquisition System
Acoustic Sensor	1-inch piezoelectric	Ceramic	Sound level meter	Condenser microphone	Optional
Measurement Units	L_{eq}	Noise exposure	L_{eq}	Percent time	Sound level
Frequency Weight	A-weight	A-, B-, C- linear weight	Not applicable	A-weight, type 2	A-, B-, C-weight or flat
Measurement Ranges	67 to 147 dB; 37 to 117 dB	9 ranges of 27 dB from base of 60	40 dB	90-115 dBA	60-100 dB
Range Switching	Manual	Manual	None	None	Auto range
Auxiliary Input	Yes	Yes	Yes	No	Yes
Signal Processing	Internal	Counter only	Counter	Amplitude/Time	Off line
Internal Calibration	No	No	Yes	Yes	Yes
Data Encoding	Not applicable	Not applicable	Not applicable	Not applicable	BCD
Sample Rate (Time)	5 seconds to 10 hours	Slow	1 msec, fast, slow	Slow	0.5, 1, 10 sec; 1, 3, 10 sec
Central Processor	Not required	Manual computation	Not required	Not required	Tape reader/computer/ calibrator
Operator Controls	On/off display range; input reset	Input, base level power, weight, K-factor	Function time constant	None	Date, time, sample time, weight, power, cal, display, event
Displays	Four digits of 7-segment display	Windows	Electromechanical counter	Four-digit LED	Four-digit LED
System Cost	$2500	-	-	-	$4000
Operating Temperature	-10°-55°C	-	-	-10°-55°C	0-110°F
Power Supply	AC continuous 24V battery, 5 hours	AC	AC, DC	Batteries	AC, DC
Weight	13 lb	10 lb	9 lb	0.6 lb	16 lb
Size	0.3 ft^3	0.3 ft^3	0.2 ft^3	0.01 ft^3	0.8 ft^3

Section 3
MONITORING APPROACHES

The monitoring approaches to be explored herein will have two basic purposes: 1) to confirm actual progress in controlling or decreasing the cumulative noise exposure levels at various points on the ground and 2) to provide a tool for controlling individual aviation-related facets of the airports' implementation plan which require cooperation by others, such as aircraft operators.

Some of the alternative monitoring approaches are given below:

a. Conventional fixed location monitoring in real-time.
b. Fixed location monitoring with on-site recorder for later batch processing at commercial data center.
c. Periodic monitoring with portable equipment.
d. Monitoring by exception.
e. Conditions when monitoring would not be required.

Each of these approaches implies a range of equipment, personnel, and methodologies required to perform the assigned task. The narration below will explore the possible range of factors which relate to each approach.

3.1 CONVENTIONAL FIXED LOCATION REAL-TIME

The monitoring approach using fixed locations which monitor in real-time implies a methodology requiring continuous evaluation of an impacted area which has been accurately defined in terms of location. Further, this methodology is not limited to the assessment of the cumulative environment but is capable of evaluating, where required, single events of interest. The data from such a concept can be used to constantly assess and revise the noise implementation plan as each noise control is implemented. Thus, this methodology implies that: 1) the impacted or encroached area is well defined; 2) measurements at the specific sites will show direct results attributable to the implementation of noise controls; 3) the data output reflects, as a minimum, the daily cumulative noise exposure and, more likely,

an hourly status; 4) single events are identifiable in some minimum terms such as time of day, location, and level; 5) the system output may be corrected for the effects of meteorological changes; 6) it is accurate so that noise reductions attributable to the implementation plan noise controls are adequately assessed; 7) some staffing will be required to operate, analyze, and maintain the system; and 8) the system capability includes self calibration.

The equipment used in the above methodology can consist of: 1) self-contained site with processor or 2) remote site with central processor. The self-contained site with processor is envisioned to include:

a. Sensor.
b. Signal conditioning circuit.
c. Processor.
d. Output device.

Such equipment would be capable of operating unattended for extended periods of time, yet the output would be readily accessible. The manpower requirements for such an approach would include such considerations as how often data is collected and reviewed, operator input requirements, and durability of equipment and installation methods.

The remote site with central processor is envisioned to include:

a. Sensor.
b. Signal conditioning equipment.
c. Signal transmission/reception system.
d. Processor.
e. Output device.

This equipment has all the attributes of the above concept except that the collection of results is centralized and, thus, any operator interaction is centralized and, in many respects, more flexible. However, the diagnosis and correction of maintenance problems will require more manpower since isolation of problems necessarily includes personnel at the central unit and at the remote site in question.

3.2 FIXED LOCATION ON-SITE RECORDING/OFF-LINE PROCESSING

The use of fixed locations with on-site recording for later batch processing implies a variety of methodologies. Fixed locations, having the capability of only recording results, may be used in methodologies where continuous real-time processing is not required, but where the data requirements may well be more detailed than those provided by other means described below. Thus, the cost of an associated processor devoted exclusively to one task is not justified. The off-line processing here is envisioned to be performed at existing data centers, either local, regional, state, or federal in nature. This approach can be used in methodologies pertaining to baseline cases, before and after studies, as periodic checks in those situations where the encroachment is impending, where implementation of noise control actions are scheduled on a long-term basis, but where continuous monitoring is not required.

The monitoring equipment envisioned would include:

a. Sensor.
b. Signal conditioning equipment.
c. Recording device.

In order to make this approach viable, the recording device should be capable of relatively long-term operation before operator attention is required. In this case, personnel requirements can be simplified to the extent that the data record is picked up and sent to the central facility. The results are received in a predetermined format for use by interested parties. Maintenance is envisioned to include replacement of major black boxes or cards.

3.3 PERIODIC MONITORING - PORTABLE EQUIPMENT

The approach of monitoring using portable equipment includes those methodologies where great flexibility of coverage is required, where the impacted area may for some reason change periodically, where only cumulative data are required, and where versatility of equipment usage is paramount. We refer specifically here to the use of the equipment by other agencies for the monitoring of noise from sources other than aircraft operations. Portable monitoring equipment state-of-the-art is advancing rapidly at this

time. It is not beyond reason that in the near future, small compact black boxes capable of accumulating a variety of noise environmental measures will be on the market. Such equipment is envisioned to include:

a. Sensor.
b. Signal conditioning equipment.
c. Processor logic.
d. Readout mechanism.

Such equipment would require a minimum of operator input, be compact and durable, require little power, and be weatherproof. Properly designed, this equipment would require a small investment in personnel and equipment and yet provide considerable flexibility of usage.

3.4 MONITORING BY EXCEPTION

In those cases where the goal of the implementation plan is to maintain the status quo, the approach of monitoring by exception may find use. The methodology to be used implies: 1) limited coverage of key areas, 2) that specific limits are prescribed beyond which either single events or cumulative measures cannot be permitted to go, and 3) that some specific action can be taken once the limits are exceeded to correct the situation. This may pertain to quotas, curfews, noise doses, etc. The equipment can include:

a. Sensor.
b. Signal conditioning equipment.
c. Limit logic.
d. Output.
e. Identification system.

This approach necessarily requires that personnel be available to take appropriate corrective action once the exceptional event occurs. In order for effective corrective action to be taken, considerable investigative effort may be required. Thus, manpower requirements can vary from case to case. The above system concept can be simple or complex depending upon the requirements of the implementation plan.

3.5 NO HARDWARE MONITORING REQUIRED

In the implementation of the Airport Noise Regulation there will be those airports where monitoring will not be required. This is defined to mean no monitoring in terms of hardware/systems requirements. However, it is felt that the no-hardware requirement should not imply that no form of vigilance be maintained. The methodology implied here includes the continual assessment by affected parties of the direction of airport growth (both positive and negative), land use patterns, and population shifts.

3.6 DETAILED HARDWARE REQUIREMENTS - ACOUSTIC MONITORING

All of the generalized monitoring approaches have several common subsystem requirements. See Table 7.

For the purposes of detailed equipment discussion we will deal first with conventional acoustical hardware and systems, and next with operational hardware and systems that might be used.

These basic approaches might be further divided into schematic diagrams such as those shown in Figure 4. Each of these approaches utilizes essentially the same elements; however, the design approach is slightly different.

3.6.1 Sensors

Sensors are here defined as microphones which can be any of the following:

a. Ceramic (includes piezoelectric crystals).
b. Condenser.
c. Electret.

These sensors must meet some basic frequency response, dynamic sensitivity range, and environmental specifications to ensure accurate data acquisition.

Desirable microphone characteristics are reliability, smooth frequency response, minimum phase distortion, high sensitivity, small size to minimize disturbance of the sound field, simplicity, and reasonable price. These traits are not always found in the same microphone. In addition to basic

Table 7. Monitoring Approach Requirements

Subsystem Concept	Sensor	Signal Conditioning	On-Site Processing	On-Site Recording	Signal Transmission and Reception	Separate Processor	Separate Output Devices
Fixed Location + Central Processor	Required	Required	Optional	Optional	Required	Required	Required
Fixed Location + On-Site Recording	Required	Required	Optional	Required	Not required	Required but can be data center	Not required
Periodic Monitoring	Required	Required	Optional	Optional	Not required	Optional	Optional
Monitor by Exception	Required	Required	Required	-	Not required	Not required	Not required
No Monitor	Not required	Not required	Not required	Not required; can be done by ear	Not required	Not required	Not required

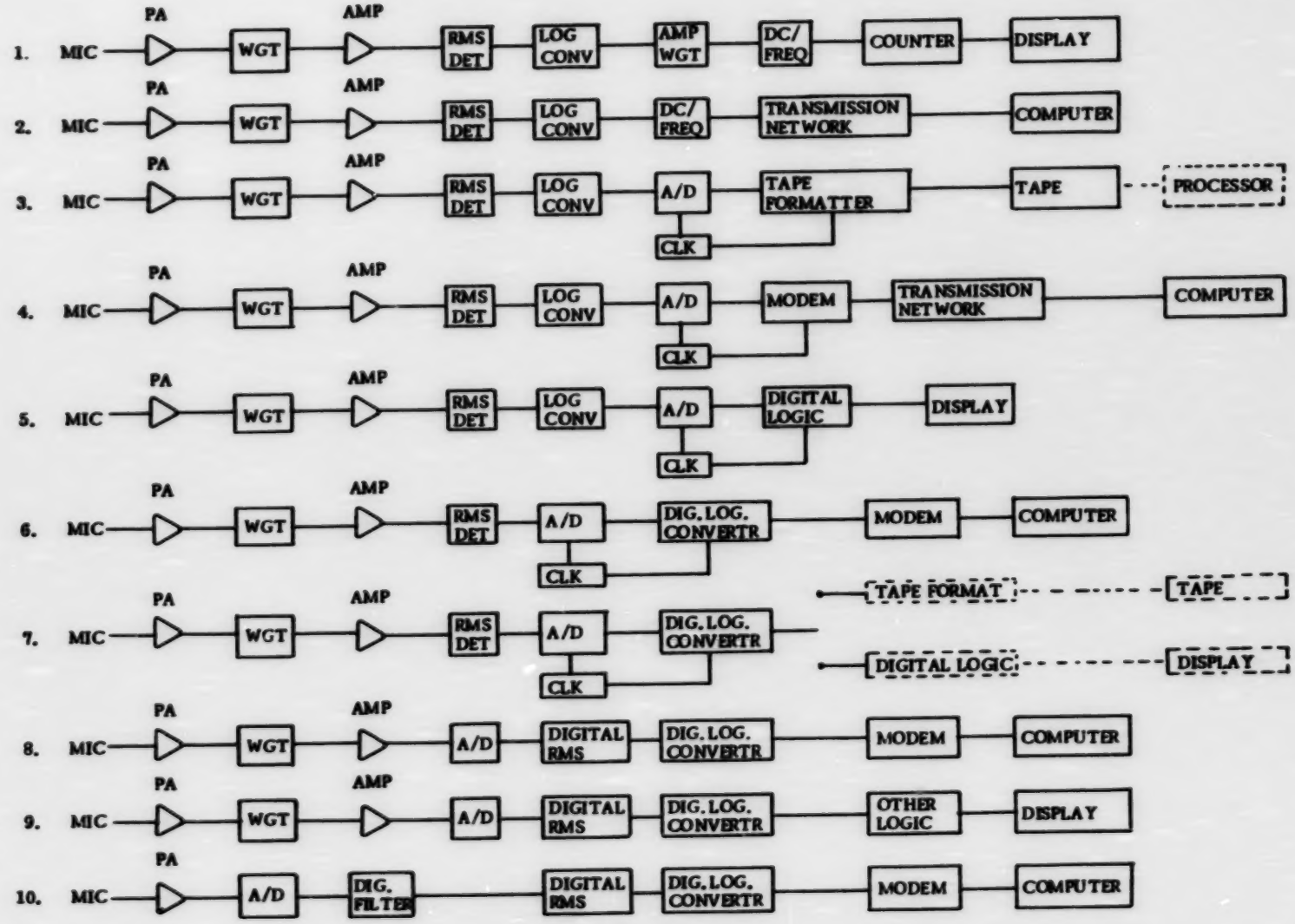

1. MIC PA WGT AMP RMS DET LOG CONV AMP WGT DC/ FREQ COUNTER DISPLAY
2. MIC PA WGT AMP RMS DET LOG CONV DC/ FREQ TRANSMISSION NETWORK COMPUTER
3. MIC PA WGT AMP RMS DET LOG CONV A/D TAPE FORMATTER TAPE PROCESSOR CLK
4. MIC PA WGT AMP RMS DET LOG CONV A/D MODEM TRANSMISSION NETWORK COMPUTER CLK
5. MIC PA WGT AMP RMS DET LOG CONV A/D DIGITAL LOGIC DISPLAY CLK
6. MIC PA WGT AMP RMS DET A/D DIG. LOG. CONVERTR MODEM COMPUTER CLK
TAPE FORMAT TAPE
7. MIC PA WGT AMP RMS DET A/D DIG. LOG. CONVERTR CLK
DIGITAL LOGIC DISPLAY
8. MIC PA WGT AMP A/D DIGITAL RMS DIG. LOG. CONVERTR MODEM COMPUTER
9. MIC PA WGT AMP A/D DIGITAL RMS DIG. LOG. CONVERTR OTHER LOGIC DISPLAY
10. MIC PA A/D DIG. FILTER DIGITAL RMS DIG. LOG. CONVERTR MODEM COMPUTER

Figure 4. Monitoring Concepts

performance characteristics the microphones must be protected from wind noise, birds, vandalism, and the adverse effects of the environment. The basic criterion has been to keep the microphone installation as simple as possible so that calibration and maintenance can be performed without elaborate precautions regarding disassembly and assembly.

Ceramic - ceramic microphones are noted for their ruggedness, stability, and reliability. Their low impedance and stable output contribute to their good performance under adverse environmental conditions.

Condenser - air-condenser microphones feature uniform high-frequency response and are suitable for operation at temperature extremes. They are available in various sizes. Because a polarization voltage is required for these microphones, they are sold only in microphone/preamplifier sets.

Electret - these microphones represent the very latest in microphone technology. They feature very uniform high-frequency performance in both flat-random and flat-perpendicular incidence versions, are available in a variety of sizes, and are economically priced. Since polarization voltage is not required, they can be used with inexpensive preamplifiers.

The basic criteria of ANSI S1.4-1971 and IEC179 are suggested for use in microphone evaluation.

3.6.2 Signal Conditioning

The signal conditioning equipment includes the preamplifier, weighting network, any special screening hardware, a signal detection and conversion network, and a signal transmission network.

The preamplifier is usually located next to the microphone sensor to minimize the effects of noise on the cable. For those sensors having very good sensitivity the preamplifier is usually close to unity gain. On the other hand, such microphones as the Chesapeake NM 135 require a low noise, high gain preamplifier to boost the signal level for transmission along the signal cable to the other signal conditioning equipment.

The weighting network is normally an A-weighting filter; however, the use of other networks such as the D or C network cannot be dismissed. It

would appear, however, that A-weighting is currently the minimum requirement. However, there may be a need to provide for a variable weighting to accommodate the various noise sources of interest.

In addition to the standard weighting, some consideration should be given to the possibility of additional frequency weighting which would serve the purpose of prescreening non-aircraft noise. Only two such systems having this feature have been used to date. The prescreening hardware is used in conjunction with software to make a decision regarding aircraft and non-aircraft noise. The use of such a network on a portable or single-site system would require careful consideration of the consequences and does not appear to be feasible and/or necessarily desirable at this time.

The signal detection and transmission can take a number of forms as outlined conceptually in Figure 4. The five basic forms represented among the ten examples given are as follows:

a. All analog.
b. Analog processing and digital transmission.
c. Semi-analog processing and digital conversion and transmission.
d. Analog filtering and digital processing and transmission.
e. All digital processing and transmission.

The acoustical monitoring concepts in Figure 4 range from simple analog portable units with real time readout by an operator (Concept 1) to a completely digital, multisite, highly automated, and computerized system (Concept 10). These ten concepts cover three types of monitoring with variations.

Type I monitoring is a field readout of portable equipment (Concepts 1, 5, 7, and 9). Type II monitoring is the field recording of data with a portable unit (Concepts 3 and 7). Type III monitoring is continuous, multisite monitoring at fixed locations (Concepts 2, 4, 6, 8, and 10).

A. Concept 1 is typical of hand held sound level meters with visual readout. This represents a low-cost approach to spot monitoring where requirements for data documentation are minimal and where manpower considerations are not of higher priority. This concept is widely used due to equipment availability and ease of operation.

B. Concept 2 is typical of early airport monitoring systems that used modified sound level meters as field units. Data from several fixed sites is transmitted to a central computer for continuous processing. This concept is applicable to medium and large airports with moderate to severe impacts. The real time aspects of this concept yield data which is useful for quickly assessing noise impact. In addition, the computer capability can be expanded to handle a number of data report formats. This particular concept is employed at several large airports, primarily in Europe.

C. Concept 3 is typical of equipment used for field surveys around an airport where the survey period ranges from a few days to several weeks. Such a concept is used in initial determination of contour locations by field measurements. This concept is also usable by small airports having moderate to light impacts or as spot checks.

D. Concept 4 is typical of more recently installed continuous monitoring at fixed sites. It employs digital techniques for data transmission and permits more sophistication in terms of data parameters acquired at the remote site.

E. Concept 5 is typical of recently introduced portable monitoring units which can accumulate noise data over selected periods of a few hours. It can accumulate and display hourly and daily noise values. It is useful at small airports for one-day measurements at selected sites. It is unique in that a single self contained unit can sum up noise levels over extended time periods. These units are relatively simple to operate and are applicable for use by a number of agencies.

F. Concept 6 is another recent implementation of continuous monitoring. It differs from Concept 4 only in that the log converter function is digital rather than analog.

G. Concept 7 also uses digital log conversion but otherwise remains the same as Concept 5.

H. Concept 8 carries continuous fixed site monitoring even more toward a digital implementation by using digital RMS detection rather than analog techniques. The advantage of digital techniques are generally improved accuracy and larger dynamic range. However, system complexity is increased in terms of operator time and maintenance requirements.

I. Concept 9 is indicative of a methodology where a field portable system supplies not only data acquisition but also all processing. This concept would encompass a very simple to operate black box which provides any number of cumulative measures which are obtained from a simple lighted display. The uses would be applicable to all sizes of airports at all levels of expertise. The cost and personnel requirements are conceived as being minimal.

J. Concept 10 is one not yet known to be implemented but represents a very highly sophisticated system capable of computing very complex cumulative measures requiring knowledge of the actual frequency content of the signal. Such a concept would be useful only in those circumstances where extremely detailed engineering data would be required on a real time basis and would imply very high costs associated with an above average level of personnel expertise.

The most interesting features of the largely digital systems are their ability to cover wide dynamic ranges using auto ranging and the ease with which computations can be made using low power digital logic. The output of these concepts are also amenable to adaptation to other types of outputs such as printers and digital cassettes.

3.6.3 Signal Transmission

The signal transmission medium, if one is used, are standard telephone lines, special cables, and radio transmissions. The transmission can be in BCD (Binary Coded Decimal) format, straight binary, or a voltage versus frequency format.

The voltage versus frequency format is used generally over telephone lines. The analog signal is made proportional to frequency and the frequency varies continuously over a finite range usually 300 to 3000 Hz, which is the common bandwidth of standard phone lines.

The BCD format is compatible with standard teletype terminals used, for example, on remote time-sharing systems. The transmission method for either straight binary or BCD is use of frequency shift keying (FSK). Two frequencies are used to denote a one or zero. The standard frequencies in use are 1020 and 1270 Hz. The same principal can apply equally well to a radio channel where two frequencies are modulated.

The use of FSK offers several advantages over the variable frequency (VCO) method. Any frequency variations on the phone lines can be easily accommodated in FSK since the bandwidth around each frequency can be fairly wide. Secondly, noise on the line at other frequencies does not degrade performance and, third, problems associated with counting the frequency are not encountered in FSK.

3.6.4 Central Processor

The central processor receives the data signal and computes the appropriate values. In addition, the central processor can also send control signals to the remote site to perform other functions such as calibrations. The central processor need not be a computer; however, for larger systems this is the case since certain operator control inputs are often desired and can be supplied less expensively with software.

For those systems not requiring two-way communication, the processor can be digital logic associated with the acquisition equipment or other small programmable calculators which can accept data hand-punched or read back into the machine through some interface.

Considerations of cost and manpower are important in choosing a processor method.

3.7 DETAILED HARDWARE REQUIREMENTS - OPERATIONAL MONITORING

Operational monitoring will here refer to those systems or equipment which record or display operational characteristics of the aircraft. Of primary importance are the positional information of the aircraft and its performance parameters.

The hardware to be discussed includes tracking systems and on-board data recorders.

Tracking systems include on-board instrumentation such as glide slope computers, vertical navigation equipment (V-Nav), visual approach monitor (VAM), and distance measuring equipment (DME). Ground based systems include visual approach slope indicator (VASI), microwave landing system (MLS), and air traffic control radars. All of these pieces of equipment are used to relate to flight track.

The use of noise abatement takeoffs and approaches requires that a number of aircraft/engine performance parameters be observed. These are as follows:

Takeoff Procedures:

- Power
- Airspeed
- Altitude
- Flaps
- Climb speed
- Deck angle

Approach Procedures:

- Flaps
- Gear position
- Altitude
- Glide slope
- Power

In order to evaluate the effectiveness of an abatement procedure it is suggested that the performance of the aircraft be monitored rather than the resulting noise, or a combination of both.

The hardware required for the above is a flight data recorder capable of multiple channel input, event identification, time, etc. The equipment

should have an output on tape so that data may be processed as required or the output could be radioed to a ground based acoustical monitor system to be correlated with noise measurements.

Specific equipment approaches are outlined in schematic form in Figure 5.

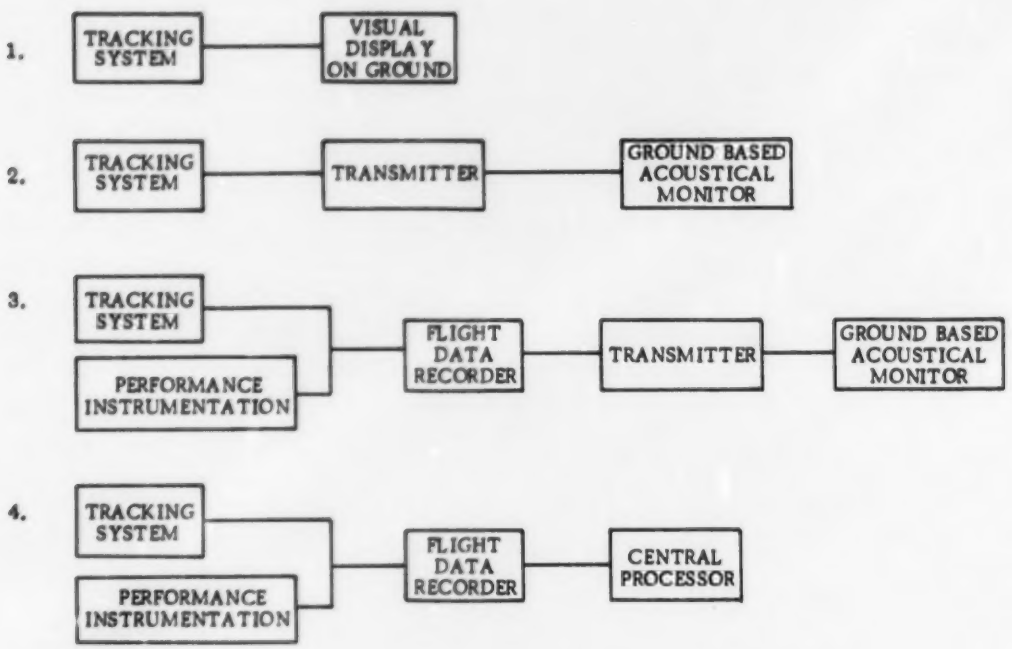


Figure 5. Operation Monitoring Concepts

The equipment outlined in System 1 of Figure 5 may be used to assess the ground track and/or approach and departure profiles of airport operations. This information can be used in initially defining those areas most commonly overflown and may be of use in assigning specific flight paths as part of a noise control plan. In addition, the altitude information may be useful in defining the need for additional navigational aids which might result in increased capability, i.e., handle two-segment approaches.

System 2 would interact with a ground based acoustical monitor where aircraft location information can be correlated with acoustical data in a

number of ways. The altitude and ground track information may be compared with preset limits which would result in single event data printouts should the tracking and/or noise limits be exceeded. In this manner the concept of noise violations may be tempered by some knowledge of operational problems.

System 3 utilizes both tracking and aircraft performance in conjunction with a ground based acoustical monitor system. Here the concept is one of not only recording inflight data, but also making that data available in a real time mode to the acoustical monitoring system. The operational information can be accumulated in some fashion to reflect number of events exceeding preset limits or it can be correlated with a particular single event. This information would permit detailed investigation of noise problem areas, both from an acoustic and operational point of view.

System 4 is visualized to be an example where flight recorder data is processed by a central facility. The processing may be performed only in those cases where noise violations occur. An alternative method of processing would yield data to aid in establishing the need for and level of training effort required to maintain some established proficiency in noise abatement procedures.

The use of operation monitoring approaches opens up an area of new problems as to how data is handled and made available to the interested parties. For example, while it is all very well to record on-board data, there are problems to be solved in identifying each takeoff/approach, of obtaining the data tapes, and processing the tapes. The question also arises as to the need for processing each data tape or only those which contain an operation which has resulted in a noise violation. Other factors to consider are that existing equipment perform very vital functions and implementation of any special purpose uses must be very carefully evaluated, not only from a technical but a philosophical point of view.

Section 4
EVALUATION CRITERIA - ACOUSTICAL SYSTEMS

The primary attributes of any monitoring system result from the monitoring approach chosen and the technical performance, operational considerations, maintenance and manpower requirements, environmental factors, and costs associated with the approach.

The evaluation criteria should cover both the overall system electronic performance and other areas relating to equipment usage. There appear to be approximately seven areas of interest, as given below, along with subfactors.

a. Overall performance.
    1. Accuracy.
    2. Linearity.
    3. Dynamic range.
    4. Versatility.
    5. Expandability.
    6. Output options.
b. Extent of coverage provided.
c. Current technology status.
d. Environmental factors.
    1. Meteorological limitations.
    2. Susceptibility to vandalism.
    3. Unsightly visual aspects of installation.
e. Physical and electrical factors.
    1. Size.
    2. Weight.
    3. Power requirements.
f. Operational considerations.
    1. Personnel requirements.
    2. Maintainability.
    3. Reliability.

g. Costs.
    1. Initial.
    2. Operating.
    3. Lease/rental.

The choice of these criteria are due, in large part, to their appearance in system or equipment specifications. They also are represented in various forms in the survey of existing systems.

The foregoing factors will be used to develop a grading scale or index to evaluate monitoring approaches. This involves three steps:

a. Define a set of grading criteria which fully reflects the performance of the approach to be evaluated.
b. Quantify the performance of each approach relative to each criteria on a scale from 0 (unacceptable) through 70 (reasonably acceptable) to 100 (perfect).
c. Calculate a weighted combination of the scores obtained for all performance criteria to obtain an overall performance index. This index is also defined on a scale from 0 to 100.

4.1 SCORING CRITERIA

Many of the factors mentioned will reflect performance attributes which are independent of each other and which do not imply particular approaches. This grading criteria then involves associating some level of performance criteria with the appropriate factors. Other criteria do not relate directly to numerical performance but can be assigned some index. The criteria and their related performance indexes are given in Table 8.

The next step is to define a function relating performance index to a numerical score. The general approach to doing this is to define three points on a curve. The three points selected are:

a. 100% - Ideal or perfect performance level.
b. 70% - Average or reasonably acceptable performance level.
c. 0 to 10% - Unacceptable performance level.

Table 8. Summary of Evaluation Criteria - Performance Indices

Evaluation Criteria	Performance Index
Accuracy	dB error
Linearity	±dB
Dynamic Range	ΔdB
Meteorological Limitations	Temperature range and humidity range and vibration level
Size	Volume
Weight	Pounds
Power	Watts or operation time
Reliability	Down time per year
Cost	Dollars
Coverage	Number of sites
Personnel Requirements	Manhours per site
Versatility	Units of measure and accessories available
Expandability	Number of sites added or removed
Technology Status	Date of design and type of circuit design
Vandalism	Number protective measures provided
Visual Aspects	Compactness
Output Options	Format and number of devices
Maintainability	Cost of service and level of service (field or factory)

4.1.1 Accuracy

The attribute chosen to reflect accuracy is dB error. An average acceptable error was chosen as ±1.5 dB, ideal as ±0.5 dB, and unacceptable error as ±3.0 dB. The resulting graphical presentation is given in Figure 6. Notice that the curve reflects the law of diminishing returns.

The selection of ±1.5 dB as an acceptable error is based on the precedent set in the existing noise standards of the State of California and the fact that systems meeting this criteria are in operation.

The choice of ±0.5 dB as an ideal score is based upon the assumption that not all errors can be eliminated from the system and that an arbitrary value of ±0.5 dB might be achieved under ideal circumstances.

The above criteria reflect, in part, the Type 1, 2, and 3 sound level meter specifications of ANSI S1.4-1971 and IEC 179.

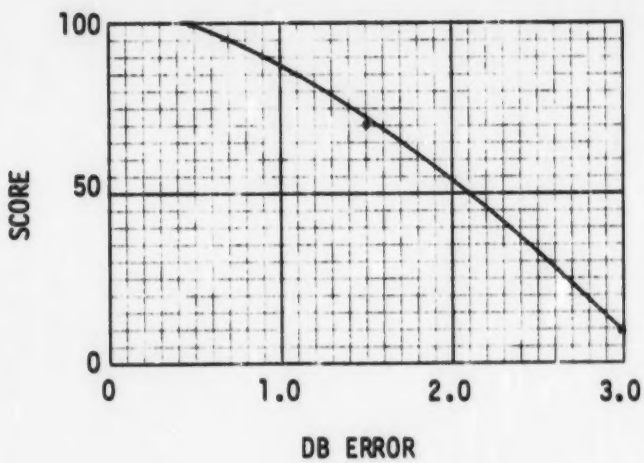


Figure 6. Accuracy Curve

4.1.2 Linearity

The linearity of a system over the entire operating range is required in order that the overall system accuracy is maintained. The linearity is required during extreme environmental changes. Since the linearity is one part of the overall system accuracy and one of the easier design goals to meet, a perfect score is assigned a value of ±0.5 dB, an acceptable score a value of ±1.0 dB, and an unacceptable score a value of ±1.5 dB. Figure 7 illustrates the curve shape.

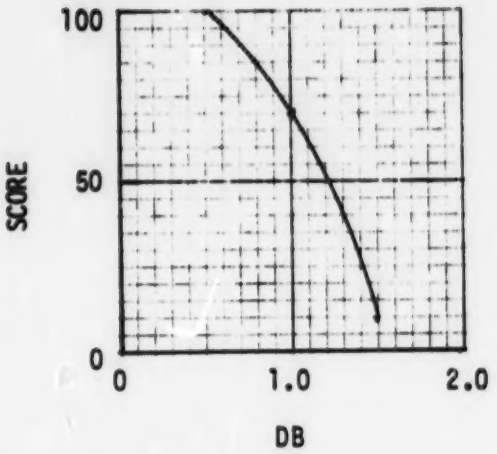


Figure 7. Linearity Curve

4.1.3 Dynamic Range

The dynamic range of the equipment is the overall measurement range expressed in decibels. This will include provisions for crest factors, to accommodate large excursions of peak-to-average signal voltages. The ideal dynamic range is defined as 100 decibels. An acceptable dynamic range is 50 decibels for airport noise monitoring and an unacceptable dynamic range is defined as anything less than 20 decibels. Figure 8 illustrates the resulting scoring curve.

An acceptable range was chosen to be 50 dB based on an examination of the spread of typical U.S. Air Carrier fleet and business jet takeoff and approach noise levels. It was found that levels varied from 75 to 120 EPNdB. If one allows for some margin of error then a 50-dB dynamic range would sufficiently cover the desired range with little or no loss of information. On the other hand, a system covering a 20-dB dynamic range is unacceptable since some portion of the data must be discarded.

The ideal dynamic range was chosen for convenience as 100 dB. There are systems currently in operation which come close to this criteria.

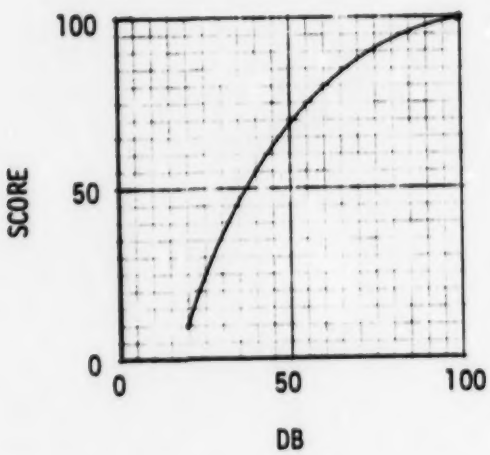


Figure 8. Dynamic Range Curve

4.1.4 Meteorological Limitations

There are several performance levels to define environmental factors. The two most important are temperature operating range and humidity range. It is pointed out here that these criteria are to be related to the remote sites, whether fixed or portable, and do not include central processing units which can be housed in office-like environments.

For microphones an additional consideration is the temperature coefficient of the sensor which must be low. In addition, the electronic circuit drift due to temperature is of importance.

The scoring of the temperature range performance is: 1) ideal - -45°C to 66°C, 2) acceptable - -23°C to 57°C, and 3) unacceptable - 0°C to 38°C, assuming a ±1 dB change. The resulting graph is given in Figure 9a.

The ideal temperature range would permit system operation at approximately 99 percent of all airports within the United States. Possible exceptions are those located in desert climates or in the extreme northern states, such as Alaska, where very extreme temperatures are experienced.

An unacceptable temperature range was chosen as 32°F to 100°F since this temperature range is very likely to be exceeded at a large number of airports.

The acceptable temperature range represents a conservative middle ground and are values that have been demonstrated in laboratory tests.

The relative humidity performance range is: 1) ideal range - 0 to 100% humidity, 2) acceptable range - 0 to 95%, and 3) unacceptable range - 5 to 90%. Figure 9b illustrates the curve. Ideally a system should perform under all relative humidity conditions, however, since the acoustical validity of data acquired under conditions of rain, snow, or fog is questionable, an acceptable range of humidity was chosen as 0 to 95%. An unacceptable range of humidity was chosen as 5 to 90%.

The combined temperature coefficients of the microphones and associated electronics is ranked as: 1) ideal - 0.018 dB/°C, 2) acceptable - 0.027 dB/°C, and 3) unacceptable - 0.036 dB/°C. The scoring curve is illustrated in Figure 9c.

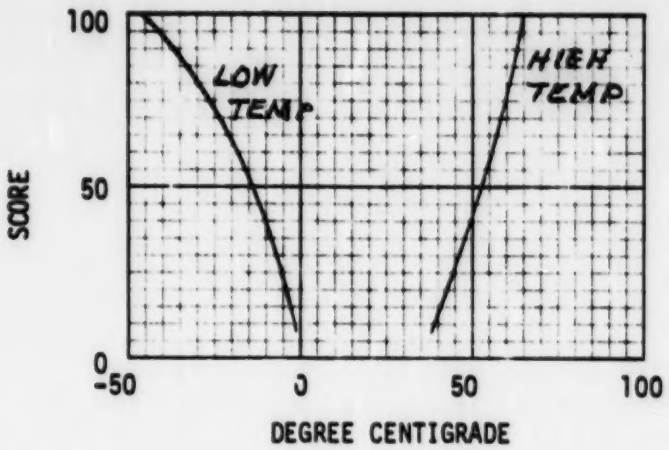


Figure 9a. Temperature Range Performance Curve

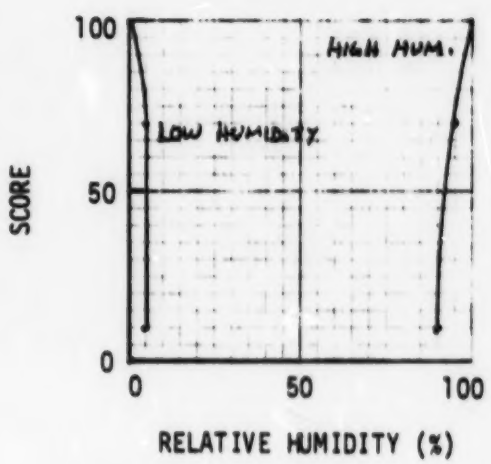


Figure 9b. Relative Humidity Performance Range Curve

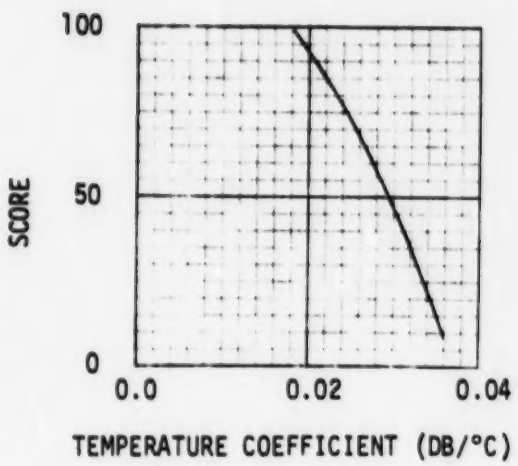


Figure 9c. Combined Temperature Coefficients Curve

4.1.5 Size

The physical size of the remote portable part of the system is a factor especially in terms of installation ease, location, visual aspects, etc. The values of scoring are based primarily upon data from available systems and some finite size of certain key components such as printers, etc.

a. Ideal - 0.03 m^3.
b. Acceptable - 0.08 m^3.
c. Unacceptable - 0.3 m^3.

The curve is shown in Figure 10.

An acceptable size was chosen as 3 ft^3 for ease of handling. The ideal size was arbitrarily chosen to be 1 ft^3 and the unacceptable size as 10 ft^3.

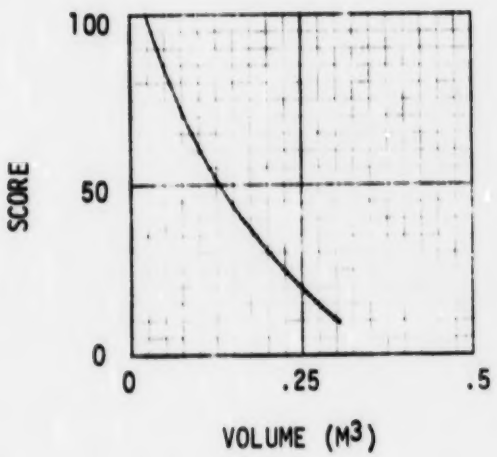


Figure 10. Physical Size Curve

4.1.6 Weight

The scoring for system weight pertains to that part of the system which is not a centrally located processor.

a. Ideal - 4 kg.
b. Acceptable - 8 kg.
c. Unacceptable - 20 kg.

The curve is given in Figure 11.

The weight of an ideal system was selected as 10 lb. This reflects the ease of handling and simplicity of structural design for installation and is only slightly more weight than a Type 1 sound level meter. An acceptable weight was arbitrarily chosen to be 20 lb and a weight of 50 lb was chosen as unacceptable from a handling point of view.

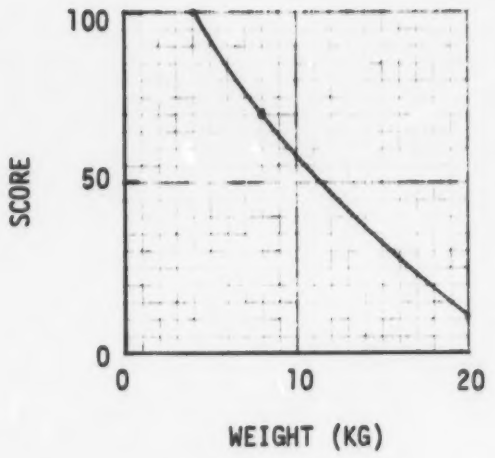


Figure 11. Weight Curve

4.1.7 Power

The power requirements associated with monitoring are based on consumption for all parts of the system except the central processing unit.

a. Ideal - 5 watts.
b. Acceptable - 15 watts.
c. Unacceptable - 100 watts.

The curve is given in Figure 12.

The choice of power consumption values was based on a primary consideration for use in portable monitoring, the important consideration ultimately being how long can the system operate before batteries must be recharged or replaced.

An ideal power consumption of 5 watts was chosen based on existing portable equipment. The acceptable level of 15 watts was an arbitrary choice. The level of 100 watts power was selected as being unacceptable for a system where portable use was contemplated.

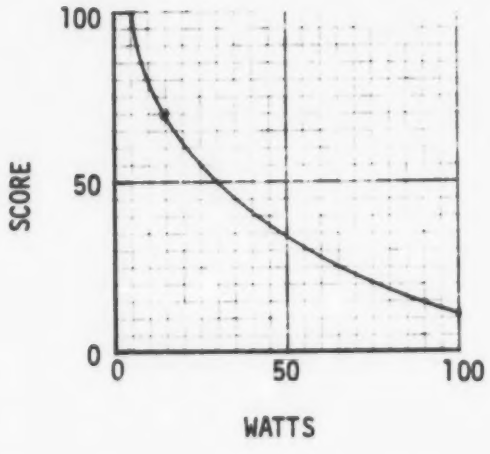


Figure 12. Power Curve

4.1.8 Reliability

The reliability of a system is reflected in many things, the classic factor being the mean time between failure. However, due to the many components that may comprise a monitoring system, another unit of measure of reliability will be used. The total operating time lost due to an equipment failure will be used as the rule. This will not only include component failures but also reflect somewhat upon the ease with which failures can be diagnosed. The period of monitoring is defined to be a year.

The ideal down time over a year would be zero. The acceptable total down time would be 2 weeks. An unacceptable total down time would be 8 weeks. The choice of an acceptable down time of 2 weeks is based on the precedent set in the noise standards of the State of California. Ideal down time would be zero weeks. An unacceptable down time of 8 weeks was arbitrarily chosen since this reflects some 15 percent of the time.

See Figure 13 for the resulting curve.

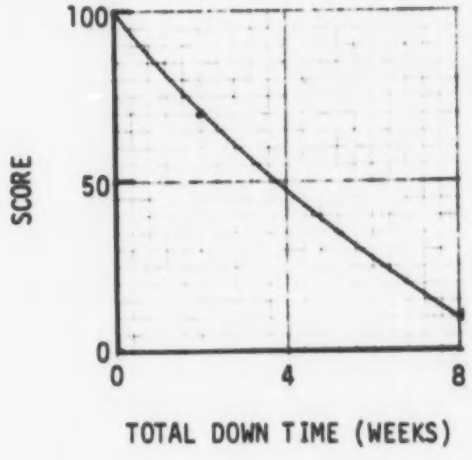


Figure 13. Reliability Curve

4.1.9 Cost

There are several types of costs that can be examined for this factor. The first will be the initial procurement cost, the second will be the yearly cost of operations, and the third will be the yearly maintenance cost.

The ideal procurement cost would be zero per site, the acceptable cost $13,000 per site, and the unacceptable cost $20,000 per site. The graph is given in Figure 14a.

The method used to arrive at an acceptable cost per site was to use historical data and then apply some cost reduction factor applicable to reductions in component prices. By discarding the least and most expensive cost per site, a figure of $17,500 is computed. Next, a cost reduction of 25 percent was assumed based on nonrecurring development costs which results in an acceptable cost of $13,000.

An unacceptable cost per site was arbitrarily chosen as $20,000 per site.

The cost of operations includes cost of power, use of transmission lines where applicable, expendable materials, deployment and retrieval costs where applicable, and the costs of publishing reports.

The ideal cost was assumed to be zero dollars. An acceptable annual cost was computed as $300 which was based on estimates of transmission line costs, power consumption, the cost of digital tapes for portable sites, and costs of processing and reporting. This cost would include a minimum number of man-hours associated with making sure the system is not malfunctioning.

An unacceptable operating cost was chosen as $1000 per site per year.

The ideal cost of maintenance is $0 per site, the acceptable cost is $300 per site, and unacceptable cost is $1000 per site. This is the same graph as that presented in Figure 14b.

The cost of maintenance was chosen to be identical to the cost of operations and reflects current maintenance costs on several existing systems.

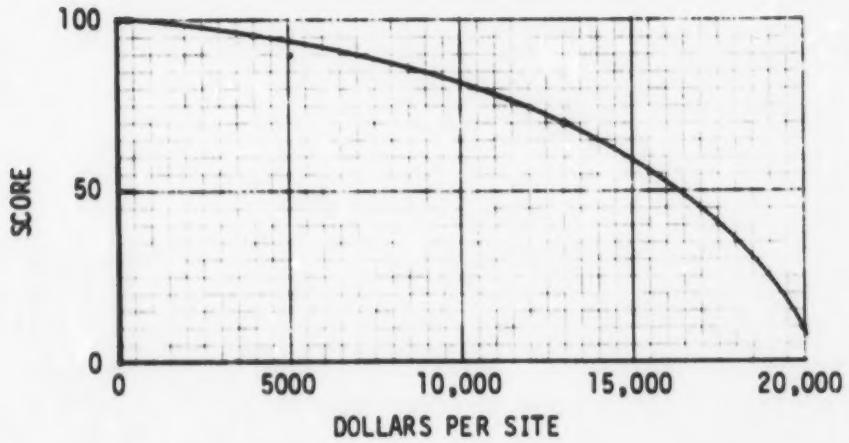


Figure 14a. Procurement Cost Curve

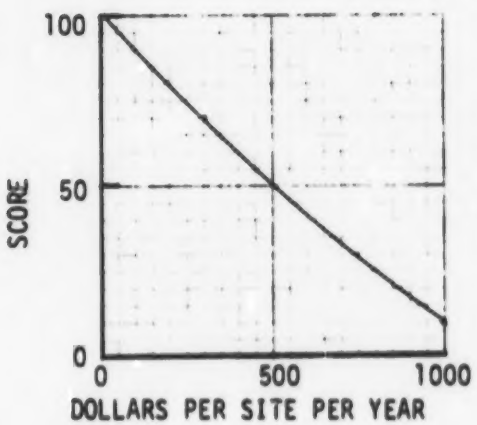


Figure 14b. Operations/Maintenance Cost Curve

4.1.10 Coverage

The concept of coverage is rated by the number of sites within the impacted area. The choice of scoring is as follows:

a. Ideal coverage is one site per each 10 units of land use index.
b. Acceptable coverage is one site per 20 units of land index.
c. Unacceptable coverage is no coverage.

The resulting graph is given in Figure 15.

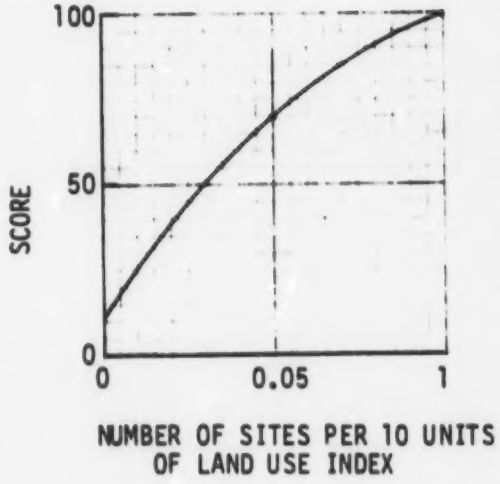


Figure 15. Coverage Curve

4.1.11 Personnel Requirements

The personnel requirements will be evaluated in terms of manhours/site per year. This includes primarily the operations, planning, data review, analysis, and public relations functions required. Maintenance manpower is not included. The level of manpower is often a function of how involved and responsive each monitoring user is to the situation. In addition, the extent of automation with regard to report formatting by a processor is a relevant factor. Therefore, the choice of ideal, acceptable, and unacceptable manpower requirements were based on a review of the survey responses. The lowest yearly manhours per site was 25 and the highest 400 manhours. These values were used as limits. A smooth curve connected these points and the resultant acceptable value of 50 manhours per site was derived.

a. Ideal - 25 hours/site.
b. Acceptable - 50 hours/site.
c. Unacceptable - 400 hours/site.

The curve is depicted in Figure 16.

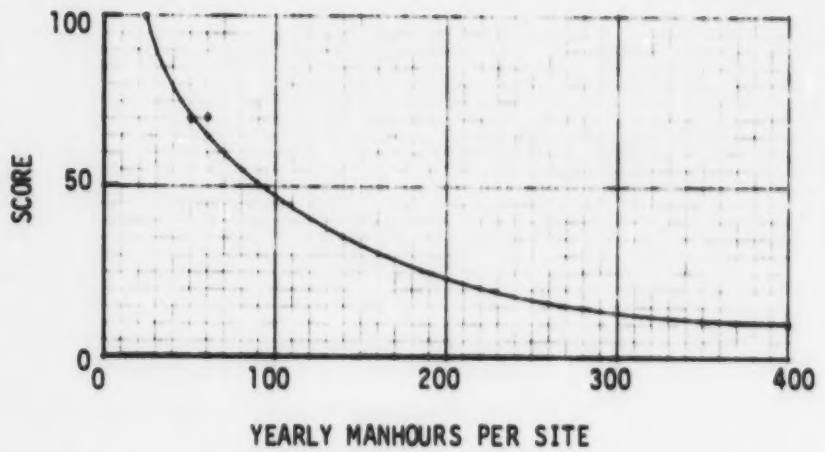


Figure 16. Personnel Requirement Curve

4.1.12 Versatility

The versatility of a system will be evaluated in terms of the number of different monitoring jobs it can accomplish. For example, a system that can perform both single event and cumulative monitoring is more desirable than a single purpose unit all other factors being equal. A general outline of versatility factors are given below:

a. Number of measures available.
b. Portable operation.

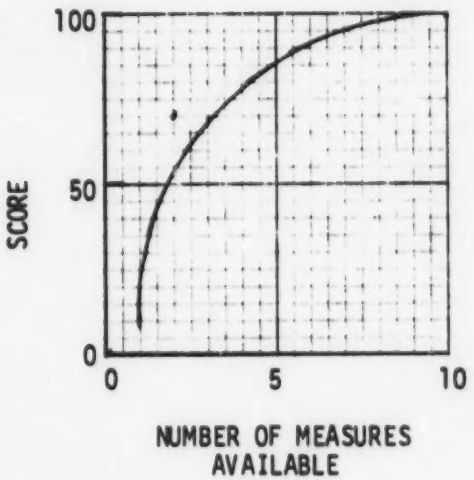


Figure 17. Versatility Curve

4.1.13 Expandability

The expandability of a system must be considered both in a positive and negative sense. On the one hand, a positive expansion may be warranted so that additional sites can be added to the network if refined data are desired. On the negative side, however, sites may be removed as the impacted area is reduced as the result of noise control measures. Thus, a score of 100 is given if sites can be added or removed. A score of 70 is given if sites cannot be added or removed.

4.1.14 Technology Status

The state-of-the-art in monitoring systems has been moving rapidly in the last few years. These advances have resulted in wider dynamic ranges, lower power requirements, and smaller equipment. Thus, the system using the latest state-of-the-art is usually the most ideal candidate.

The state-of-the-art will be denoted by the year of system design. The current year 1974 is scored as 100, with the year 1972 being acceptable and the year 1970 being unacceptable. Note that the current year will always be designated as a score of 100.

See Figure 18 for the resultant curve.

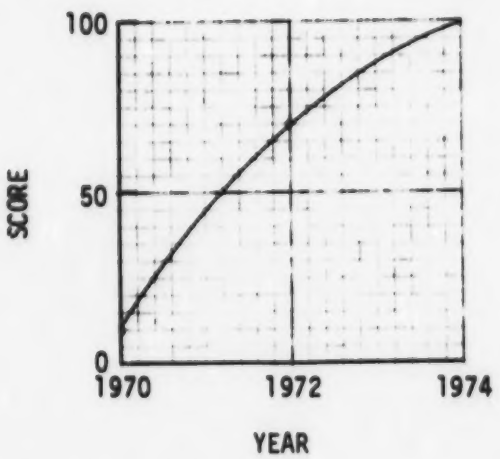


Figure 18. Technology Status Curve

4.1.15 Susceptibility to Vandalism

This area might also be labeled durability. One of the most pressing problems when monitoring is the requirement for placing equipment where it is accessible for maintenance, easily installed, but not subject to undue exposure to vandalism. The factors to be considered here would include durability of enclosure, ease of attachment, and sensor protection.

The enclosure must be durable and lockable to receive an acceptable score of 70. In addition, the sensor must be protected to receive an acceptable score. Note that no ideal score is given.

4.1.16 Visual Aspects

The aesthetics of the system are important from two aspects. First, some sites may be located on residential property, thus the overall installation should be compact and pleasing to the eye. Secondly, some sites and central units are on display in public places. Thus, the quality of aesthetics may be of importance in imparting a sense of confidence in the overall monitoring concept.

The rating score of this area will be assigned to the key descriptors of compactness. This relates to the overall number of separate boxes or units that may comprise a site. The goal is to attain a minimum number of units, hopefully small, for each installation.

The ideal is one unit, the acceptable is two units, and an unacceptable score is three or more units.

See Figure 19 for the curve.

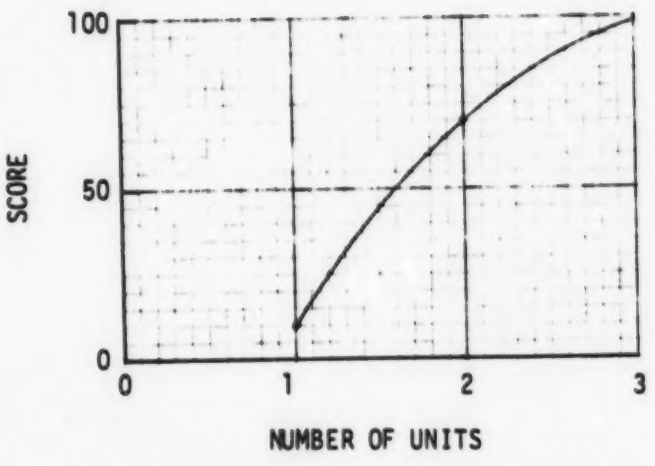


Figure 19. Visual Aspects Curve

4.1.17 Output Capabilities

The rating of output capabilities will be focused upon the type, format, and availability (immediate or future) of results. The type is here referred to mean the number of measures values available from one system. The format reflects the form of the output including analog, digital, light emitting diodes, etc. The availability of output is scored in terms of real time output versus off-line output. The amount of hand calculation is also of consideration.

Ideal scores are given for: 1) five output measures, 2) a digital format, and 3) real time results. The acceptable score is given for: 1) one output measure, 2) analog or light format, and 3) off-line results. An unacceptable score is not considered.

See Figure 20 for the resultant curve.

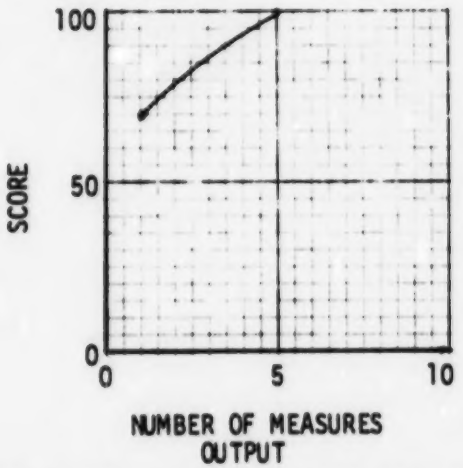


Figure 20. Output Capabilities Curve

4.1.18 Maintainability

The problems associated with maintenance include not only manpower cost but also availability of repair services and spare parts availability. The cost of maintenance to the airport is considered. In addition, the level of maintenance available (field, regional, or factory) and the amount of effort required to obtain service and parts (mail or technical representative) must be evaluated. The ease of reaching the equipment is also considered since some systems require lift trucks to reach sensors.

The results of the survey indicated that a low of 30 and a high of 75 manhours per site per year were used for maintenance. It is assumed that this covers periodic preventative maintenance as well as emergency maintenance. Therefore, an acceptable value was chosen as 30 manhours per site per year. The unacceptable value was chosen as 60 manhours per site per year and an ideal value as 10 manhours per site per year.

The scoring for manhours per site per year is as follows:

a. Ideal - 10 hours.
b. Acceptable - 30 hours.
c. Unacceptable - 60 hours.

The primary electronics of the system must be reachable without special lift trucks, etc, to receive an acceptable score.

The level of service must at least be available at the factory to receive an acceptable score. Spares availability from the factory is also acceptable.

See Figure 21 for a curve of the manhours rating.

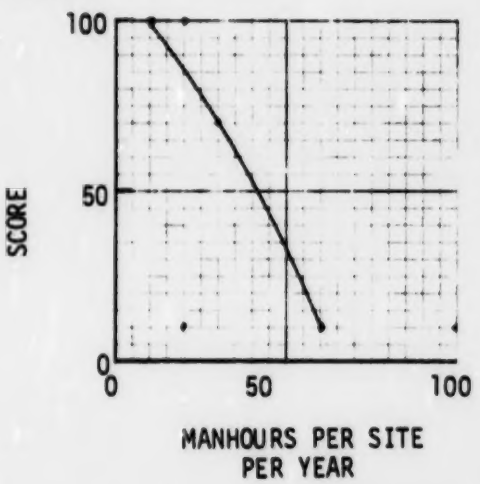


Figure 21. Maintainability Curve

4.1.19 Summary Table of Scoring

A summary of the evaluation criteria, performance indexes, and scoring criteria are given in Table 9.

Table 9. Scoring Summary

Evaluation Criteria	Performance Index	Score		
		100	70	10
Accuracy	±dB	±0.5	±1.5	±3.0
Linearity	±dB	±0.5	±1.0	±1.5
Dynamic Range	dB	100	50	20
Meteorological	Temperature range	-45 to 66°C	-23 to 57°C	0 to 38°C
	Humidity range	0 to 100%	0 to 95%	0 to 90%
	Temperature coeff	0.018 dB/°C	0.027 dB/°C	0.036 dB/°C
Size	Volume	0.03 m^3	0.08 m^3	0.3 m^3
Weight	Weight	4 kg	8 kg	20 kg
Power	Watts	5	15	100
Reliability	Total weeks down time	0	2	8
Cost	Procurement - $/site	0	13,000	20,000
	Operations - $/site	0	300	1000
	Maintenance - $/site	0	300	1000
Coverage	Site per 10 units of land use index	1 per 10	1 per 20	0
Personnel	Manhours per site	25	50	400
Versatility	No. measures available	10	3	1
	Portable	Yes	No	-
Expandability	Can sites be added	Yes	No	-
	Can sites be removed	Yes	No	-
Technology Status	Date of system design	1974	1972	1970
Vandalism	Enclosure durable	-	Yes	No
	Enclosure lockable	-	Yes	No
	Sensor protected	-	Yes	No
Visual Aspects	Compactness	1 unit	2 units	3 or more
Output Options	No. measures output	5 hr	1 hr	-
	Format	Digital	Analog/lights	-
	Output availability	Real time	Off line	-
Maintainability	Manhours/site/year	10 hr	30 hr	60 hr
	Reached from ground	-	Yes	No
	Level of service	Field	Factory	-
	Spares availability	Local distribution	Factory	-

4.2 CALCULATING OVERALL PERFORMANCE

The technique suggested for calculating an overall performance grade from a weighted combination of the various scores for each performance criterion is based on the use of a parallel combining model. Three combining models were considered. These were:

a. Series (linear).
b. Multiplicative.
c. Parallel.

The first two were rejected for reasons described as follows.

4.2.1 Series Model

For the series model, the overall grade, G, is simply the weighted sum of the scores for each performance criterion.

$$G = W_1 S_1 + W_2 S_2 + \ldots + W_N S_N$$

or

$$\boxed{G = \sum_{i=1}^{N} W_i S_i} \qquad (4\text{-}1)$$

where

S_i is the score (0 to 100) for the ith performance criterion

W_i is the relative weight for the ith criterion

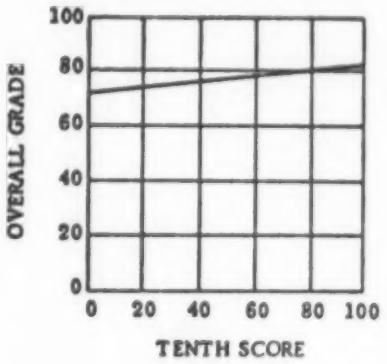
The weights W_i are chosen to reflect the relative importance of each criterion in terms of overall performance. A constraint is placed on the weights if it is desired that the overall grade G equals the individual scores S_i for the case where all the scores are the same. The constraint is

$$\sum_{i=1}^{N} W_i = 1 \qquad (4\text{-}2)$$

This ensures, for example, that if the individual scores are all 70 then the overall grade is also 70. For the case of equal weights, $W_i = 1/N$ and the overall grade is just the average of the individual scores.

This model is called the series model because the scores are combined in the same manner as resistors connected in series in determining the overall resistance.

The primary objection to the series model is that when a significant number of scores are being combined, the overall grade is not very sensitive to individual scores - even though overall performance can be greatly affected by an individual performance level. This can best be illustrated by considering a case where ten scores are to be combined with equal weights. Suppose nine of the scores are 80, and the effect on the overall grade of the tenth score is plotted. The result is shown below.



It can be seen that when the tenth score varies from 0 to 100, the overall grade varies only from 72 to 82. An acceptable overall grade of 72 can be obtained even though the performance level relative to the tenth criterion is unacceptable (score of 0). It is this feature of the series combining model which makes it unacceptable as a means of calculating an overall performance grade truly representative of the overall performance level.

In the above example, equal weighting was assumed. The conclusion does not change if unequal weights are employed. If one score is more heavily weighted, the other scores have even less effect on the overall grade than that shown in the example.

4.2.2 Multiplicative Model

To correct the above deficiencies, a combining model is required which has the following feature. If an individual score goes to zero, the overall grade should go to zero regardless of the other scores. One such model is the multiplicative model defined by Equation 3 below.

$$G = S_1^{W_1} S_2^{W_2} S_3^{W_3} \ldots S_N^{W_N}$$

or

$$\boxed{G = \prod_{i=1}^{N} S_i^{W_i}} \qquad (4\text{-}3)$$

Here, each score is weighted by means of an exponent. A constraint on the weights is that the overall grade must equal the individual scores if all the scores are the same. The constraint is

$$W_1 + W_2 + \ldots + W_N = 1$$

or

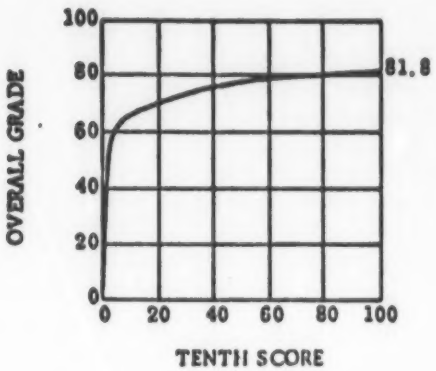
$$\sum_{i=1}^{N} W_i = 1 \qquad (4\text{-}4)$$

just like in the series model.

It is now of interest to see how the overall grade is affected when ten scores are combined with equal weights. As before, assume nine of the scores are 80. The variation in the overall grade with the remaining score (say S_{10}) is

$$G = (80^{0.9})\, S_{10}^{0.1}$$

This is plotted as follows.

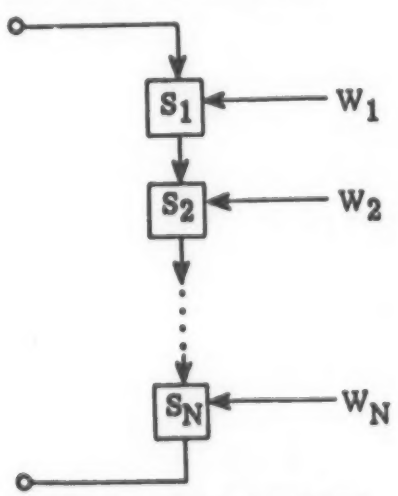


It can be seen that the overall grade goes to zero as required when the tenth score goes to zero. However, the overall grade is not significantly reduced until the tenth score gets very close to zero. When the score drops to 10, for example , the overall grade drops only to 65.

It is concluded that although the multiplicative combining model has the required feature of going to zero for any zero score, it is not sufficiently sensitive to low (but non-zero) scores to yield a true representation of the overall performance level.

4.2.3 Parallel Model

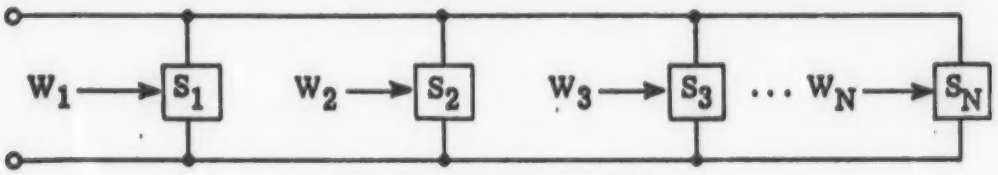
The series model was called that because the scores are combined in the same manner as resistors connected in series. The method of combination for the series model is shown schematically below.



Series Combining Model

It can be seen that if one of the resistors goes to zero, the overall resistance does not go to zero, but equals the sum of the other resistances.

Another combining model can be obtained by a parallel rather than series connection of the elements. The parallel combining model is shown schematically below.



Parallel Combining Model

It can be seen that this model has the required feature that if one element goes to zero, the overall resistance also goes to zero.

Mathematically, the parallel combining model is

$$G = \frac{1}{\frac{W_1}{S_1} + \frac{W_2}{S_2} + \ldots + \frac{W_N}{S_N}}$$

or

$$\boxed{G = \frac{1}{\sum_{i=1}^{N} \frac{W_i}{S_i}}} \qquad (4\text{-}5)$$

As before, the constraint on the weights requires that the overall grade equals the individual scores when the scores are equal. This requires that

$$\sum_{i=1}^{N} W_i = 1 \qquad (4\text{-}6)$$

which is the same constraint as placed on the other models.

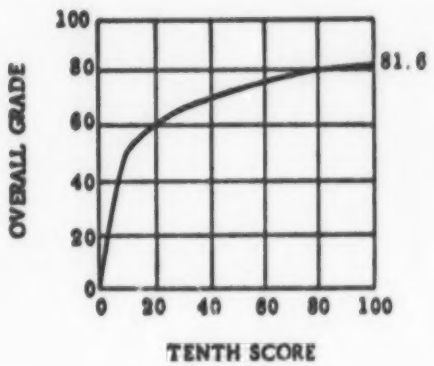
It is now of interest to examine the sensitivity of the overall grade to one score when the other scores are held at a constant value of 80. For equal weighting and ten scores to be combined, the overall grade is

$$G = \frac{1}{\frac{1}{10}\left(\frac{9}{80} + \frac{1}{S_{10}}\right)}$$

or

$$G = \frac{800\,S_{10}}{80 + 9S_{10}}$$

This is plotted below.



Comparing this plot to the results for the multiplicative combining model, it can be seen that for the parallel model the overall grade is much more sensitive to low values of an individual score. Because of this desirable feature, the parallel combining model is selected as the best choice to combine scores of individual performance criteria into an overall performance grade.

In order to illustrate the rank-ordering scheme, an arbitrary example is given below. It is assumed that there are six criteria for three systems having the hypothetical weights and scores given in Table 10. Using the parallel model, the overall performance grade is that given at the bottom of the table.

Table 10. Example of Performance Grade

CRITERION	W_i	SYSTEM NO. 1 S_i	SYSTEM NO. 2 S_i	SYSTEM NO. 3 S_i
ACCURACY	0.25	80	50	70
RELIABILITY	0.15	75	60	75
AREA COVERAGE	0.15	85	70	75
STATE OF THE ART	0.20	70	70	30
VERSATILITY	0.10	70	75	65
MODIFICATION POTENTIAL	0.15	60	80	60
OVERALL PERFORMANCE GRADE		73	64	55

Note that System 1 scored consistently except for modification potential. System 2 scored well except for a very low score on accuracy, which is weighted highly. System 3 might be described as being acceptable, but old. The low score in the category of state-of-the-art therefore results in an overall low ranking.

It should be noted that the above example used several weighting factors. Since the weights, W_i, are chosen to reflect the relative importance of each criteria in terms of the performance, the particular scenario will play a part in the choice of values assigned.

The considerations to be used in determining the weighting value for these situations will include the importance of the criteria in maintaining quality of data, the applicability of each criteria to the situation, the constraints of real life, and the knowledge gained in previous monitoring applications.

Section 5
EVALUATION CRITERIA - OPERATIONAL SYSTEMS

The evaluation criteria to be used in rating the performance of operational systems, especially those related to existing equipments, will be limited to basic considerations such as:

a. Suitable data output availability.
b. Data handling problems.
c. Degree of interference with normal function.
d. Degree of system uniformity.
e. Methods and standards for data interpretation.
f. Regulatory problems.
g. Cost of implementation.

The above are very fundamental issues which must be applied on an industry-wide basis.

The technical factors to consider are accuracies of tracking systems as well as accuracies of on-board engine/aircraft performance instrumentation.

At this point, further research of these equipments are needed in order that specific scoring can be applied.

Section 6
RESEARCH NEEDS

The monitoring of airport noise has been under way for a number of years now. The sophistication of the systems or equipment used has depended in some part on the current availability of the marketplace. As a consequence, the philosophy of "let's do the best with what is available" has often prevailed.

A number of technical problems have been overcome; however, there are some areas which would warrant additional attention. For example, the microphone/preamplifier combination is usually the weakest part of any system, especially from an environmental point of view. Although one can obtain weatherproof microphones, it would be desirable to know the absolute limitations of non-weatherproof units. For example, certain ceramic microphones are quoted as operable in 100-percent humidity; however, recent information available to this contractor indicates that prolonged exposure to high humidity results in a frequency response change, attributable to an impedance change. Thus, even though the unit can operate in high humidity, its accuracy may be affected. The change was in the low frequencies and this effect on A-weighted results should be evaluated.

A systematic evaluation of the humidity performance of microphone/preamplifier systems currently in use would be useful in determining the limitations of use.

During the course of discussion on monitoring approaches it has been suggested that such devices as dosimeters be considered for use in airport noise monitoring. It is suggested that additional research be performed in this area by comparing outputs from an existing monitoring system with that of a dosimeter mounted at the microphone.

The aspects of operational monitoring, especially the use of on-board data recorders is a relatively new idea. Although, on the surface, the instruments appear attractive, such questions as uniformity of recording

format, tape handling problems, event identification, data processing requirements, and performance standards must be investigated. It is suggested that an in-depth review of current literature be pursued regarding equipment and that selected airlines be interviewed regarding their own operational procedures used to handle flight recorder data. Further, the questions relating to regulatory procedures must be addressed.

Because of the wide range of airport monitoring systems available and the resultant procedures peculiar to each, it may be of extreme interest to perform a small comparative study to assess side-by-side performance. The effort is envisioned to be one of locating several types of commercially available equipment at the same spot, recording or acquiring data for a selected time period and comparing the results. In addition, an evaluation of equipment handling problems, calibration requirements, technician input, and detailed data processing input requirements can be determined on a comparative basis. It is suggested that an existing monitoring system be used as the baseline and that one of the existing sites be selected.

Such a side-by-side comparison will quickly evaluate the relative importance of many system factors from a truly operations point of view.

Section 7
PLANS FOR PHASE II OF STUDY

The foregoing generalized monitoring approaches will be fully developed in terms of technical feasibility and limitations, costs, and capability to provide meaningful results.

When all possible approaches have been completely documented, an evaluation will be conducted. The evaluation will use the grading index developed in Phase I. The evaluation will be quantitative and use the parallel model previously discussed. In this way, the final index developed for each approach will not be an obscure procedure. It will be logically evident what factors resulted in a particular approach, scoring high or low.

It is anticipated that each approach will be evaluated for two or three particular airport situations. Depending on the airport noise implementation characteristics, the weighting factors (i.e., W_1, W_2, W_3, ...) of the parallel evaluation model will vary. This means the index rating for a given approach will be high or low, depending on the airport situation.

When this evaluation is complete a comparison will be made of the merits (i.e., individually weighted factors) as well as overall index rating. The selected family of approaches will be used in drafting a proposed performance standard for inclusion in the noise regulation. Table 11 lists topics which should be addressed in the regulation. It is important that the regulation distinguish between end result performance requirements and implementation techniques. The California noise standards, for example, intermingle the two and performance requirements are sometimes defined in terms of implementation. This has necessitated clarification by the state when implementations vary from those in the laws. A similar situation to a lesser extent exists with FAR 36, which has required interpretation from the FAA. In the case of the EPA noise regulation, the distinction is even more important in that the regulation covers a wide range of airport situations, rather than a specific event (certification) or airport contour verification (California noise standards).

Table 11. Proposed Regulation Topics

1. Parameter of Noise Level Measurement (i.e., NEF, CNEL)
2. Number of Monitoring Sites
3. Location of Monitoring Sites
4. Measurement Period
5. Randomization of Measurement Periods
6. Technical Requirements of Site Surroundings
7. Technical Requirements of Monitoring Equipment
8. Special Cases Requiring Monitoring
9. Reporting Requirements

The proposed outline for work on the Phase II report, therefore, is as follows:

a. Expand generalized monitoring approaches to include an array of specific equipment for various scenarios.
   1. Microphones and preamplifiers.
   2. Signal detection and conversion systems.
   3. Data recording or transmission systems.
   4. Processing systems.

b. Calculate the weighted score of monitoring approaches assuming at least three classes of use.
   1. Large airport.
   2. Medium airport.
   3. Small airport.

c. Evaluate the scores in Item b in terms of reasonableness and economic impact. Revise scoring criteria where applicable.

d. Rank order the monitoring approaches and develop a set of performance specifications and procedures for regulation.

The critical issues to be resolved in Phase II will be a determination of the need for new or modified equipment approaches and procedures to satisfy the many varied monitoring demands and a determination of the level of effort to be expected in terms of manpower and cost and reporting requirements.